No institution in Britain, nor p
in the whole world, has influenc
modern Science more than that
splendidly successful research
laboratory at Cambridge, the
Cavendish. Here, for the first time,
is its whole story, telling of the
fundamental scientific ideas and
discoveries which originated there,
and of the great men who worked
in it, such as Sir J. J. Thomson who
discovered the electron, Lord
Rutherford, the New Zealand
farmer's son, who first split the atom,
and the Russian Peter Kapitza.

It was in the Cavendish that Sir James Chadwick discovered the neutron and that Sir John Cockcroft and E. T. S. Walton transmuted, for the first time completely artificially, the atoms of one element into those of another. There, too, the cloud chamber—which allows us to see something of the invisible world of the atom—was invented by C. T. R. Wilson and perfected by P. M. S. Blackett.

It has been said that 'the Cavendish gang ran the second world war scientifically and technically'. In more recent times, the research workers there probed deep into the secrets of Nature; Perutz and Crick are cracking the code by which heredity transmits the characteristics of living organisms from one generation to another; and Martin Ryle looks, with his radioastronomical observatory, into the farthest corners of the universe up to nine thousand million light years away in time and space. In all probability the Cavendish will one day provide the indisputable answer to that age-old question about the origin and development of the cosmos.

FRANKLIN WATTS, INC.
575 Lexington Ave. · New York 22

THE CAVENDISH LABORATORY
NURSERY OF GENIUS

The Cavendish Laboratory

NURSERY OF GENIUS

by

EGON LARSEN

with a foreword by

SIR JOHN COCKCROFT, O.M., F.R.S.

ILLUSTRATED

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FOREWORD BY

SIR JOHN COCKCROFT O.M., F.R.S.

Master of Churchill College, Cambridge

THE foundation of the Cavendish Laboratory in 1871 started a new era in British Physics—the development of the School of Experimental Physics which was to lead to such tremendous developments in our knowledge of the physical world and equally important consequences in the world of industry. The Laboratory has been fortunate throughout the ninety years of its existence in being directed by a sequence of great scientists—Clerk Maxwell, Rayleigh, J. J. Thomson, Rutherford, Bragg—whilst the post-war generation of scientists led by Sir Nevill Mott are continuing the great tradition of discovery in new fields. During this period, Maxwell's theory of electro-magnetic waves led to the development of radio communication. Rayleigh, his successor, was one of the greatest classical physicists of all time, whose work is still extensively consulted. J. J. Thomson discovered the electron and Rutherford the atomic nucleus, and showed how to transmute it. Bragg, a pioneer in applying X-rays to the structure of crystals, returned in 1938 to develop the study of the structure of the all-important biological molecules, such as proteins, and out of this has come the discovery of the chemical basis of heredity.

The Laboratory has traditionally worked on the 'do-it-yourself' principle—working with one's own hands to build a large part of the equipment used. It is fortunately set in an intensely stimulating intellectual environment, and it is fed by a stream of very gifted research students from the Cambridge Colleges and from the Universities of the world. These factors, together with its inspired leadership, have been responsible for its success.

I hope that this book will inspire young people to take up the study of science seriously.

I

The Age of Experimenting

'EXPERIMENTING is unnecessary for the student,' said the great Cambridge mathematician, Dr Isaac Todhunter, in the 1860's. 'The student should be prepared to accept whatever the master told him.'

The professors, of course, did experiment—or science and technology would not have progressed very far beyond the point they had reached a century and a half ago. But they were given hardly any facilities, and had to work with makeshift equipment. When, for instance, William Thomson, later Lord Kelvin, taught at the University of Glasgow in the 1840's, he took over an old wine cellar in his predecessor's house; he threw out the bins, installed a water supply and a sink, and called the room a physical laboratory: it was the first of its kind at a British university. There was, however, not much systematic instruction in that laboratory; Thomson picked among his students a 'volunteer corps' to help him in his research work.

In that wine cellar Thomson and his group did some remarkable work, and it was their achievements which stimulated the setting-up of laboratories in other universities. This was not just an outward change in the form of research and teaching; it reflected the effects of the great social changes in the country. During the Industrial Revolution, the new class of manufacturers had risen to the top and required technical ideas and men who could carry them out—just as in earlier centuries the merchants needed astronomical research and instruments to get their wares from faraway countries. Now it was the steam-engine, the machine tool, and later electrical gear of all kinds which were wanted by the manufacturers, and these things could not be designed or perfected without research into the

properties of matter. This was the reason why there grew a sudden interest in physics, and why specialists and engineers were needed. The universities had to turn them out for the new ruling class, but they could not have done this without experimenting, without laboratories.

The Clarendon Laboratory in Oxford, begun in 1868 and completed in 1872, was an important sign of this new recognition of the 'progressive' sciences, as compared to mathematics and 'natural philosophy' which had dominated the colleges. There was, of course, a good deal of opposition to the change, and Dr Todhunter was only one of many professors who spoke against it. But the teaching of practical physics was on its way, and Cambridge decided that it must now have its own laboratory; a commission was appointed to consider the matter, and its report, published in 1869, recommended the appointment of a Professor and a Demonstrator, the provision of a lecture room, classrooms, a large laboratory, and a stock of physical apparatus.

The amount of money which the laboratory would cost—the estimate was £6,300—seemed frightening, but the Chancellor of the University offered to pay for the building out of his own pocket. He was the seventh Duke of Devonshire, whose family name was Cavendish; he was a descendant of the great scientist, Henry Cavendish. The site for the new buildings was soon found. In 1762 the University had bought land for its Botanical Garden; gradually it became cluttered up with buildings, and the garden was no longer of much use. The University had tried to get rid of the site in Free School Lane by leasing it as a market-place or something of this kind, but without success. Now the land seemed just right for the erection of the new buildings. They were built at a cost exceeding the original estimate, £8,450, but the Duke paid up without a murmur. The main part containing the lecture room and the laboratory was ready for use by the Michaelmas term, 1873, and the name bestowed on the building was that of its illustrious benefactor, Cavendish.

Meanwhile, the University authorities looked around for a suitable man for the new professorship. Lord Kelvin would

have been the obvious choice, but he did not want to leave Glasgow. There was, though, a man whose personality seemed to be just right for that nursery of physicists which, in a later age, acquired by right its byname of Nursery of Genius—James Clerk Maxwell.

Born at Edinburgh in 1831, he had already at the age of fifteen sent a scientific paper on the 'Description of Oval Curves' to the Royal Society of Edinburgh; he studied in his native town and at Cambridge University. At twenty-five he was appointed Professor of Natural Philosophy at Aberdeen, and four years later to the same position at King's College, London. He had retired to his Scottish estate in 1865, but when the authorities of the University unanimously approved, in 1871, his election as Professor of Experimental Physics, he accepted. This appointment showed great foresight, for Maxwell's most important work was still to come—indeed his genius was not fully appreciated until long after his death, as we shall see.

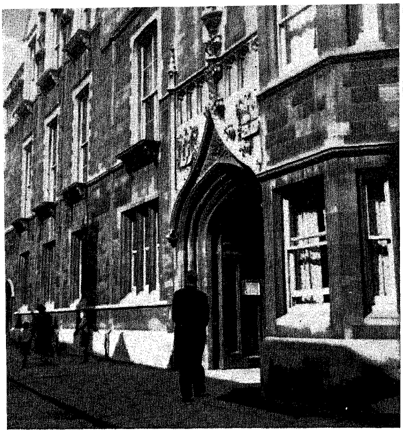
But he had already made a name for himself by his work on the kinetic (movement) energy of gases; according to his theory, which was later found to be more or less correct, the gas molecules, or clusters of atoms, are in ceaseless motion in space, and their kinetic energy depends on the temperature of the gas. Maxwell considered the molecules to be perfectly elastic particles which collide with each other and with the walls of the container in which the gas happens to be. He explained the phenomena of the molecular world in imaginative analogies, one of them being what came to be called 'Maxwell's demon': a minute being with faculties fine enough to follow individual molecules; this demon was in charge of a kind of sliding door, separating two compartments of a vessel filled with gas. Every time a fast-moving molecule moves from left to right, the demon opens the door, but he closes it when a slow molecule approaches. Thus the fast-moving, heat-producing molecules accumulate in the right-hand compartment, which grows hot, while the slow-moving ones remain in the left-hand compartment. This demon theory was to explain the concentration of diffused energy.

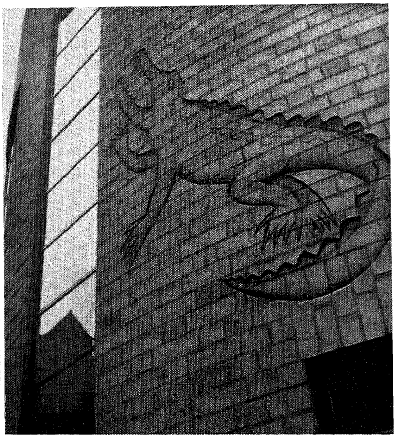
Maxwell's range of interests was extremely wide. Among the pieces of equipment he used, which can still be found in a small collection of apparatus at the Cavendish Laboratory, is a *zoetrope*, or 'wheel of life', the forerunner of the cinematograph; it is a Victorian toy based on the inertia, or laziness, of our eye, which blends two still images into a single one if they quickly follow one another—thus a series of pictures showing phases of movement creates the impression of continuous movement when viewed through the slits of a rotating zoetrope. Maxwell himself painted such picture strips to demonstrate the principle to his students. He also devised a colour top and colour box in order to analyse colour vision and colour blindness, dynamical tops to demonstrate the motion of a rigid body rotating about its centre of gravity, and other pieces of apparatus based on his boyhood toys.

'Experiments of illustration may be of very different kinds,' he said in his first address after his appointment. 'Some may be adaptations of the commonest operations of ordinary life, others may be carefully arranged exhibitions of some phenomenon which occurs only under peculiar conditions. They all, however, agree in this that their aim is to present some phenomenon to the sense of the student in such a way that he may associate with it the appropriate scientific idea. When he has grasped this idea, the experiment which illustrates it has served its purpose.

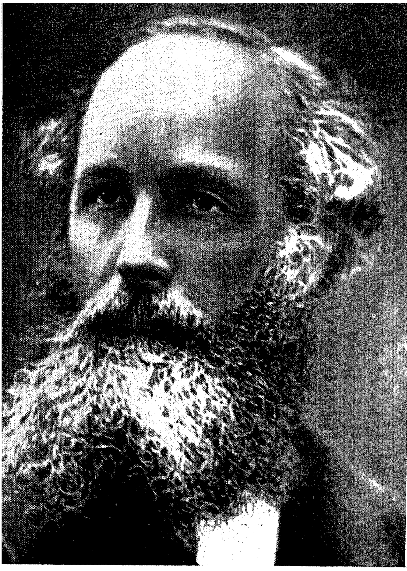
'In an experiment of research, on the other hand, this is not the principal aim. It is true that an experiment, in which the principal aim is to see what happens under certain conditions, may be regarded as an experiment of research by those who are not yet familiar with the result; but in experimental researches, strictly so called, the ultimate object is to measure something which we have already seen—to obtain a numerical estimate of some magnitude.

'Experiments of this class—those in which measurement of some kind is involved—are the proper work of a physical laboratory. In every experiment we have first to make our senses familiar with the phenomenon; but we must not stop here, we must find which of its features are capable of measurement, and

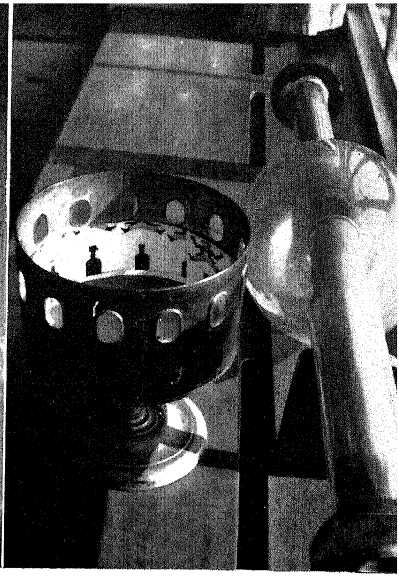




I, II and III. (Top left) *Front of the Cavendish Laboratory today.* (Top right) *Eric Gill's crocodile above the entrance to the Mond Laboratory, which was opened in 1933. The crocodile was the gift of Professor Kapitza.* (Below) *Professor Sir Nevill Francis Mott, the present holder of the Cavendish Chair of Experimental Physics*

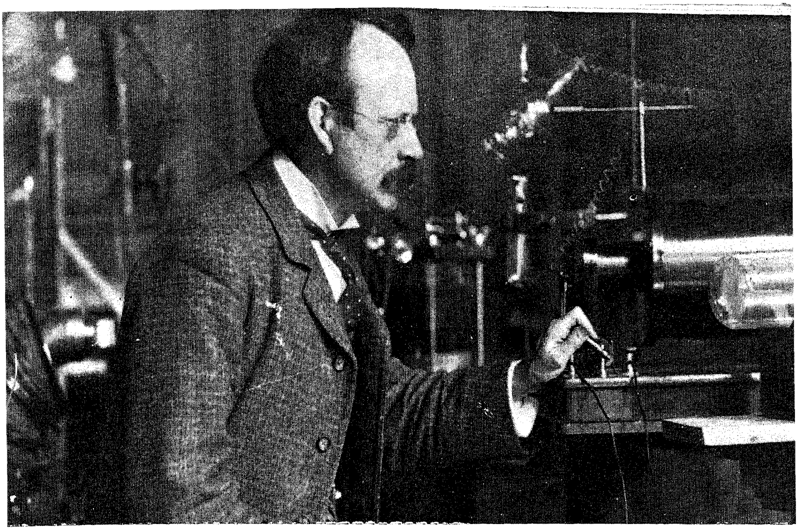


IV. *James Clerk Maxwell, who was unanimously chosen as the first Professor at the Cavendish in 1871.*

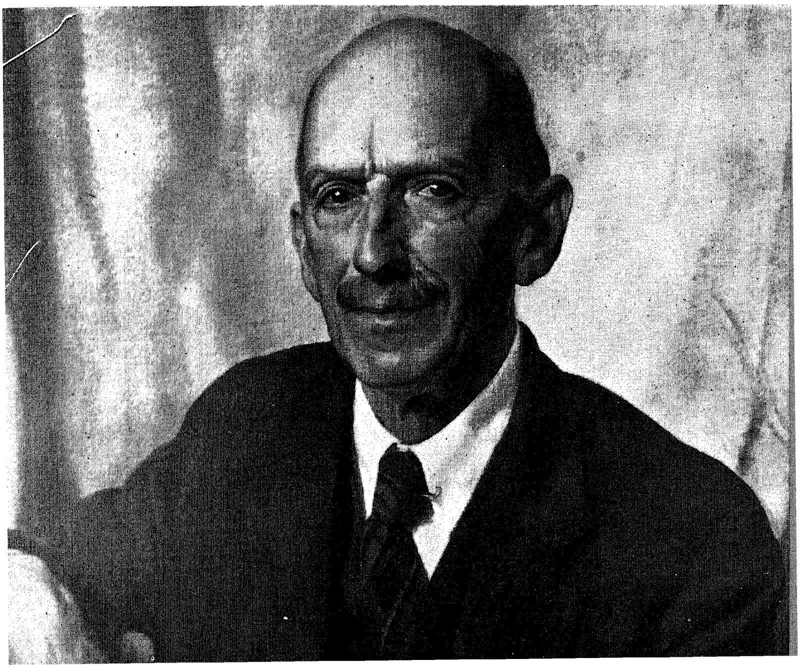


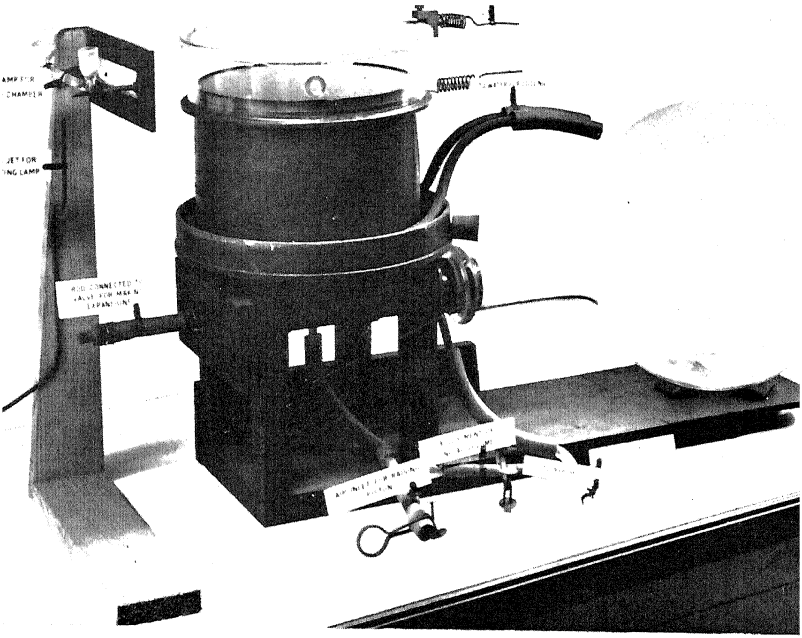
V. *Two exhibits from the Cavendish's collection of historical instruments. The circular zoetrope was used by Maxwell.*

VI. *Picture strips drawn and painted by Maxwell himself, for use in the zoetrope or 'wheel of life'—a forerunner of the cinematograph. The instrument depends on the inertia of the eye, which blends two still images into a single one if they quickly follow one another. When viewed through the slits of a rotating zoetrope, a series of pictures showing phases of movement would create the impression of continuous motion.*

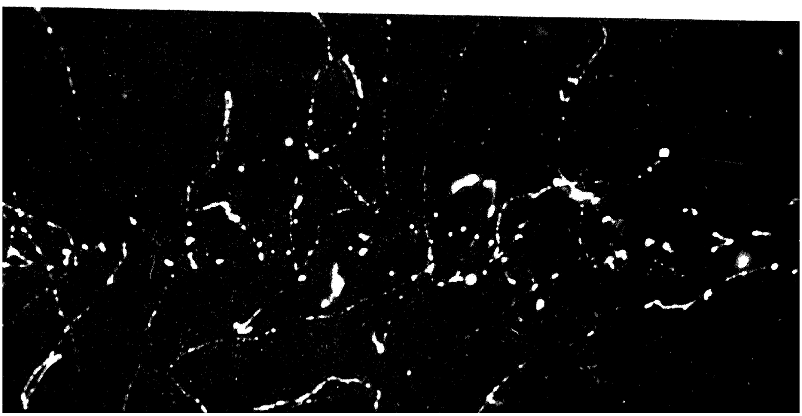


VII and VIII. (Top) '*J. J.*'—*Professor Joseph John Thomson, Cavendish Professor from 1884 to 1919, whose most famous achievement was the discovery of the electron in 1897. 'J. J.' retained his association with the Laboratory till his death in 1940.* (Below) *C. T. R. Wilson, the inventor of the cloud chamber.*





IX and X. (Top) *Wilson's original cloud chamber. This first model, still to be seen at Cambridge, was made in 1911; for over twenty years the cloud chamber had perhaps more influence on physics than any other piece of apparatus, and a number of most important discoveries were made with its help. It 'made the invisible visible'—by its aid the tracks of particles could be observed and photographed.* (Below) *Photograph of particle tracks in the cloud chamber.*



what measurements are required in order to make a complete specification of the phenomenon. . . .

'This characteristic of modern experiments—that they consist principally of measurements—is so prominent that the opinion seems to have got abroad that in a few years all the great physical constants will have been approximately estimated, and that the only occupation which will then be left to men of science will be to carry on these measurements to another place of decimals.

'If this is really the state of things to which we are approaching, our laboratory may perhaps become celebrated as a place of conscientious labour and consummate skill, but it will be out of place in the University, and ought rather to be classed with the other great workshops of our country, where equal ability is directed to more useful ends. But we have no right to think thus of the unsearchable riches of creation, or of the untried fertility of those fresh minds into which these riches will continue to be poured. . . .'

With these words, Maxwell had outlined magnificently the general plan of the Cavendish Laboratory and its underlying idea. He then explained that he would arrange the lectures according to the natural phenomena they were dealing with, such as heat, electricity, magnetism, and so on. Thus the work of the Cavendish began.

For the students entering the new laboratory it must have been a unique experience to work with tops and coils and balances and other pieces of equipment which—and this became the rule rather than the exception at the Cavendish—they themselves had to design and make by hand, with or without the help of a skilled craftsman.

During the first half-dozen years of its existence, however, there were never more than twenty students doing experimental work in the Laboratory, a number which rose only slowly to about a hundred by 1885. But Maxwell did not mind. His original idea was to attach to the Laboratory a small band of graduates, as he did not think it would be much used by undergraduates. Only three years after the opening did elementary

lectures for medical students begin; these proved to be more popular, later developing into the largest science classes in the University. Also, Maxwell would not open the Laboratory to girls for several years, and when he eventually did so it was only during the Long Vacation while he himself was in Scotland.

'Maxwell generally gave a couple of courses of university lectures per year, which, however, were shockingly neglected,' recalled Sir Ambrose Fleming, one of the great pioneers of wireless telegraphy and radio. 'I remember my surprise at finding a teacher whom I regarded as in the very forefront of knowledge lecturing to three or four students as his only audience. In fact, during one term Professor Maxwell gave a course of splendid lectures on electrodynamics, the only audience being myself and another gentleman.'

Even a lecture devoted to such a wonder of science as the telephone does not seem to have attracted many students. There were elaborate preparations; wires were laid from the basement to the attics, with telephones attached to each end. The Professor at one end and the demonstrator at the other then tried to communicate with each other, but according to Maxwell's own account the problem was to prevent the demonstrator's voice reaching him through the brick walls so that the electric current would get a chance to compete!

Maxwell took a very active part in every kind of research in the Laboratory. He used to do a daily round, enter the various rooms, and talk to the students, discussing some results here and making a few suggestions there. He was happiest when he spoke about the problems that happened to occupy his mind. Often he seemed to be the prototype of the absent-minded professor; he was then liable to ignore completely some question put to him, or to answer with something entirely different. Occasionally, however, he answered an apparently unnoticed question fully the next day—it must have trickled down in his mind and occupied it only later. 'You asked me a question the other day,' he would then say, 'and I have been thinking about it'—an opening remark which usually led to a highly interesting and original answer.

But he was far from being a dry or stodgy character. He could relax splendidly, and even compose verse. Among the songs which remained popular programme items at students' gatherings was one by Maxwell, entitled 'Rigid Body Sings', which begins:

> 'Gin a body meet a body
> Flying through the air,
> 'Gin a body hit a body,
> Will it fly?—and where?
> Ilka impact has its measure,
> Ne'er a ane hae I,
> Yet a' the lads, they measure me,
> Or, at least, they try!

Maxwell was not a healthy man; in fact, when he had left London at the age of only thirty-four he had done so for health reasons. But he did not hesitate to carry out experiments in which he himself was the guinea-pig. Henry Cavendish's writings, a great mass of which had been left unpublished, excited his interest, particularly those on electricity. He edited them, and was especially fascinated by the way in which Cavendish had anticipated later discoveries. There was in the 1790's no known effect of the electric current which could be measured by a precision instrument, and Cavendish had the idea of turning himself into a galvanometer—by estimating the intensity of the shock he received when the current was suddenly sent through his body. Maxwell repeated the experiment, and whoever visited the Laboratory at the time had to submit to it, too. Some visitors, however, failed to appreciate the originality and efficiency of the method; there was, for instance, a young American astronomer who had travelled thousands of miles to make Maxwell's acquaintance and get perhaps some hints on astronomical subjects—but instead he was made to listen to a lengthy talk about Cavendish, and more or less forced to take off his coat, plunge his hands into basins of water, and submit himself to a whole series of electrical shocks!

In 1873, the year when Maxwell actually began his work at the Cavendish, his treatise on electricity and magnetism

appeared. In this he put into mathematical form what Faraday, a quarter of a century earlier, had expressed in his 'Thoughts on Ray-Vibrations': that waves of light are waves of electric and magnetic force. 'Many powers act manifestly at a distance,' wrote Faraday. 'Such powers are presented to us by the phenomena of gravity, light, electricity, magnetism, etc. . . . The view which I am so bold as to put forth considers, therefore, radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together . . . the kind of vibration which, I believe, can alone account for the wonderful, varied, and beautiful phenomena of polarization. . . .'

And now Maxwell: 'As I proceeded with the study of Faraday, I perceived that his method of conceiving the phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols. . . . For instance, Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centres of force attracting at a distance: Faraday saw a medium where they saw nothing but distance: Faraday sought the seat of the phenomena in real actions going on in the medium; they were satisfied that they had found it in a power of action at a distance impressed on the electric fluids. . . .'

The result of Maxwell's work was what we now call the Faraday–Maxwell theory of electromagnetic waves. He concluded that light was an electromagnetic phenomenon; that light and electromagnetic waves are identical in kind, though different in wavelength. His theory was accepted by some physicists in England but hardly appreciated abroad; after all, there seemed no possibility of proving the existence of these electromagnetic waves.

Maxwell died in 1879 at the age of only forty-eight. His death was a great blow to the young Laboratory, and his students felt it as a personal loss. Always he had encouraged them, even when he believed that a student was on a wrong track. 'I never try to dissuade a man from trying an experiment,' he would say; 'If he does not find what he wants, he

may find out something else.' He had ushered in the age of experimenting; and it was another man's experimenting, eight years after his death, which showed Maxwell's true genius.

'Vertical electric vibrations, in wires stretched in straight lines, discovered; wavelength, 3 metres,' ran the entry in the diary of the German physicist, Heinrich Hertz, one day in November 1887. Looking back, we may call Hertz's experiment the first transmission and reception of a wireless message. 'I think,' he added modestly when submitting the report on his experiments to his teacher Helmholtz, 'that the electrical oscillations here utilized might be of great service to the electrodynamics of unclosed circuits.' Today we know that what Hertz demonstrated with his little inductor as a transmitter and a wire ring with two metal balls as a receiver was the beginning of wireless telegraphy, radio, television, radar, remote control. At the time, however, it was merely proof that James Clerk Maxwell had been right.

II

The Dairy Lord

SCIENTIFIC discovery might have taken a much slower and more tortuous course in the last two decades of the nineteenth century if the cows at Terling, Essex, had yielded more milk and produced more calves in 1879. As it was, the owner of the estate found himself in a difficult financial position, and therefore decided to accept the offer from Cambridge University to become Maxwell's successor in the chair of experimental physics.

His name was John William Strutt Rayleigh, third baron, born in 1842. Entering Trinity College, Cambridge, in 1861, he chose to study natural science because it fascinated him. At the age of twenty-nine, ten years later, he married the sister of Arthur Baldwin, later the Earl of Baldwin, the statesman. He valued the independence he enjoyed as a landowner at Terling, which permitted him to carry on with his research work, but at times the estate caused him a good many headaches. Later he made a successful effort to cut out the middlemen in the retail trade of farm produce; in 1887, he opened the first shop with the legend 'Lord Rayleigh's Dairies' in Great Russell Street, London, which was followed by more in different parts of the city—eventually there were eight. The milk carts in the streets of London bearing his name made him as well known among the general public as his astonishing discoveries did among the scientists. At the end of his life, in 1919, Rayleigh's farm had about 800 cows and sixty milkers.

He had set up a small private laboratory at his home in Terling, and it has been said that much of the 'Cavendish tradition' started here, among 'sealing wax, string, rough unplaned woodwork, and glass tubes joined together by bulbous and unsightly joints'. But when he moved into the Cavendish,

he expected something more elaborate. What there was in the way of equipment for experiments seemed to him quite inadequate. 'There is no steam-engine or other prime mover,' he complained in his first annual report, 'nor among the acoustical apparatus is there any musical instrument.' So he started an 'Apparatus Fund', to which he himself made the first contribution of £500. The main trouble was that there was too little demand for scientific equipment, and therefore there were hardly any instrument-makers. Rayleigh had to order the devices he needed from the Department of Engineering, but some were made at the Cavendish itself; he engaged an efficient mechanic, Mr George Gordon, a Liverpool shipwright, who set up the workshop which later was to become such an important part of the Laboratory for the building and maintenance of instruments, both for lectures and for research work.

Another difficulty was the lack of textbooks in experimental physics; those that existed were already outdated. Rayleigh asked his two demonstrators, R. T. Glazebrook (afterwards head of the National Physical Laboratory, Teddington) and W. N. Shaw (afterwards Director of the Meteorological Office), to produce a series of manuscripts describing the experiments carried out during the course; these manuscripts were eventually published as *Glazebrook and Shaw's Practical Physics*, one of the first textbooks of this kind.

The classes were still rather small; Lord Rayleigh's students attending his lectures on the use of physical apparatus and on galvanic electricity and electromagnetism numbered no more than sixteen or eighteen. As to his own research work, he took up the task of accurate determination of electrical standards, and formed a small team from his students to help him. The British Association Committee had issued a resistance coil which was supposed to represent 1 ohm, but there were some doubts whether this was correct; leading physicists had tried to make a more accurate determination, but they all worked with primitive instruments, and each of them arrived at another result—the differences amounting to up to 4 per cent. Today, the collection of apparatus at the Cavendish contains a spinning

coil with which Rayleigh and his team did the job, and on the brick pillar in the end room on the ground floor there is a brass plate recording the fact that here the spinning-coil apparatus was set up with the help of which the ohm was determined to a very high degree of accuracy in 1882. Thus Rayleigh had made an extremely important contribution not only to physical research but also to the fast-growing electrical industry, for the ohm is one of the three fundamental units of electrical measurement.

The delicate question of women students was settled in the same year. Maxwell had permitted them to enter the sacred grounds of men's endeavours only in his own absence during the Long Vacation, and in fact a number of determined girls came to go through complete courses, such as one on electrical measurements, in those few weeks. But this was not good enough. In 1882, women were admitted for the first time to the Tripos examinations, and at the suggestion of Rayleigh it was at last decided that all classes and demonstrations were to be open to girl students of the Newnham and Girton Colleges on the same terms as to the University students.

Lord Rayleigh found his work at the Cavendish rather strenuous, and he felt that he wanted to devote still more time to his own researches. He had written no less than sixty papers on an immense variety of subjects, from measuring sound by the suspended-disc method to the resolving power of telescopes. Under him, the Cavendish within five years established itself firmly as a modern institute of teaching and research work. In 1884, however, he was elected Professor at the Royal Institution in London, and tendered his resignation. He held a farewell tea-party on the fifth anniversary of his election to the Cavendish professorship, and returned to Terling the following day.

It was on his farm, in his makeshift laboratory, and at the Royal Institution that his most brilliant research work was done. His observation, in 1895, that nitrogen obtained from air had a greater density than that liberated from its compounds led him and Sir William Ramsay to the discovery of argon, an important inert gas, which is now used to fill electric light bulbs.

Rayleigh's range of studies included the dynamical theory of gases, optics, capillarity, the mechanics of flight, pure mathematics, the telephone, hydrodynamics, photography, the theory of sound, alternating currents—and psychical research, the study of such puzzling phenomena as telepathy and faith-healing, haunted houses and spirit messages.

He was awarded the Nobel Prize for physics in 1904 and was President of the Royal Society for four years. In 1908 he became Chancellor of the University of Cambridge, keeping a benevolent eye on the Cavendish, and taking time off on his farm whenever he could to inspect his beloved cows.

III

'J. J.' and the Electron

'To my great surprise, and, I think, to that of the rest of the University, I was chosen to succeed Lord Rayleigh. I remember I was told at the time that one well-known college tutor had expressed the opinion that things had come to a pretty pass in the University when mere boys were made professors,' wrote Joseph John Thomson. The young Manchester-born mathematician, then a lecturer at Trinity College, where he had also been a student, was indeed a surprising choice as Rayleigh's successor. Kelvin had again been approached, but had again decided to remain at Glasgow. Glazebrook and Shaw, the two demonstrators, excellent and experienced physicists, had both hoped to be elected. But Thomson was chosen over their heads although he was a mathematician, and a mere twenty-eight years old. Glazebrook was especially disappointed. 'Forgive me if I have been wrong in not writing before to wish you happiness and success as Professor,' he wrote to Thomson early in 1885. 'The news of your election was too great a surprise to permit me to do so. I had looked on you as a mathematician, not as an experimental physicist, and could not at first bring myself to regard you in that light.'

Why was Thomson chosen? The Vice-Chancellor of the University explained the appointment: 'Professor J. J. Thomson combines a great amount of mathematical knowledge with, as I am assured, an experimental skill which promises to make him, in the long tenure of office to which he may look forward, a worthy successor of the two distinguished men by whom the Cavendish Professorship has been occupied.' This gives us the clue to the decision of the University authorities: Maxwell had been a sick man, Rayleigh had been too easily tempted to

leave the Cavendish; but Thomson was young, healthy, and had no strong ties outside Cambridge.

It was an inspired choice, although it was not quite true that Thomson had 'experimental skill'. On the contrary, he was 'very awkward with his fingers', as one of his assistants said; 'I found it necessary not to encourage him to handle the instruments.' Professor Aston, who worked with him from 1910 onwards, has another story to tell, which shows that Thomson, although no experimenter himself, had an almost uncanny grasp of the way in which the experimental instruments had to be used:

'When hitches occurred, and the exasperating vagaries of an apparatus had reduced the man who had designed, built, and worked with it to baffled despair, along would shuffle this remarkable being who, after cogitating in a characteristic attitude over his funny old desk in the corner and jotting down a few figures and formulae in his tidy handwriting on the back of somebody's Fellowship Thesis or an old envelope or even the Laboratory cheque-book, would produce a luminous suggestion like a rabbit out of a hat, not only revealing the cause of the trouble, but also the means of cure. This intuitive ability to comprehend the inner working of intricate apparatus without the trouble of handling it, appeared to me then, and still appears to me now, as something verging on the miraculous, the hall-mark of a great genius.'

There was another point in which those who had advocated Thomson's professorship proved right. His association with Cambridge lasted throughout his life, which ended in 1940 at the age of eighty-four; he remained at the Cavendish for no less than thirty-four years. It is indeed difficult to imagine 'J.J.', as everybody called him, as a young man. He appeared, for instance, to be as stingy as usually only old people are; in fact, lack of money forced him to run the Cavendish on a sum which today covers no more than its telephone bill! Often the employees had to run after him for their money. It was J.J.'s reluctance to pay for elaborate equipment which established the 'sealing-wax-and-string' tradition of experimenting at the

Cavendish, in continuation of Lord Rayleigh's way of conducting his private experiments at Terling. But J. J. did, as one of his first acts, give the students a reading-room; it was equipped not with books purchased for this purpose but with the late Sir James Clerk Maxwell's library, which J. J. got from Maxwell's widow.

Many stories—true or invented—describe J.J. as a typical example of that now-extinct species, the absent-minded professor. There was no telling what part of his attire he might forget to put on. Once his wife rang the Laboratory: 'Have you seen my husband? How was he dressed?' She was assured that he seemed to have the usual things on, and she heaved a sigh of relief. She had found his trousers on the bedroom floor and was convinced that he had gone out in his pyjamas. In fact, he had bought a new pair of trousers without telling her.

'Immediately after my election to the professorship I began . . . some investigations on the discharge of electricity through gases, and since then I think there has never been a time at which I have not had some experiments in hand on this subject,' recalled J.J. 'I was led to investigations on this subject by having come to the conclusion that whenever a gas conducts electricity some of its molecules must have been split up, and that it is the molecules which have been thus modified which impart electrical conductivity to the gas; in short, that a gas in which all the molecules are in the normal state must be a perfect insulator. My idea at that time was that some of the molecules were split up into two atoms, one of which was positively, the other negatively electrified, and my first experiments were intended to test this idea. It was not until 1897 that I discovered that the decomposition of the molecules was of quite a different type from ordinary atomic dissociation; then I found that one of the bodies into which the molecules split up, the one carrying the negative charge, is something totally different from an atom and is indeed smaller in mass than one thousandth part of the smallest atom known.'

With these few words J.J. described, in the most concentrated and modest form possible, the major achievement of his

career—the discovery of the electron, which stands at the beginning of all atomic research. But there is a good deal more to the story of that brilliant success than J.J.'s own account reveals. The year 1895 brought two entirely unrelated events which, however, proved to be of the greatest importance to the research work done at the Cavendish. The first was a change in the regulations of the University covering the admission of students from other universities. It meant that graduates from any country were permitted to come as research students, and ever since the Cavendish has been the meeting-place of young scientists from all over the world. One of the first of these graduates from overseas was a farmer's son from New Zealand by the name of Ernest Rutherford.

The Great Exhibition of 1851 in London had shown an appreciable profit, and Prince-Consort Albert had decided that it should help in the education of promising young scientists. Ernest Rutherford, who had already won a junior university scholarship at Christchurch, New Zealand, was offered another scholarship at Cambridge University from Prince Albert's fund. When he received the letter he happened to be on holiday at home, digging potatoes in the back garden. His mother handed it to him; he read it, threw down the spade and said, 'Mother, that's the last potato I'll dig!'

The money for Ernest's passage to England had to be borrowed from friends. In the autumn of 1895 he arrived at the Cavendish, welcomed by J.J., who soon took a liking to the lanky, twenty-four-year-old New Zealander with the thinly sprouting moustache.

The other event was the discovery of a strange new kind of rays, which were called X-rays because of their mysterious nature, by Professor Wilhelm Konrad Röntgen at the University of Würzburg in Bavaria. It was at the Cavendish Laboratory that the two met—Ernest Rutherford and the X-rays, with far-reaching consequences for the history of science, indeed for our whole planet.

One day in 1895, Professor Röntgen was carrying out a series of experiments on electric discharges in vacuum tubes.

He used an instrument which had been invented by an English scientist, Sir William Crookes, and was therefore called 'Crookes' tube'; today we know it by the name of cathode-ray tube: an oblong glass vessel from which the air has been pumped out, with one metal plate at each end, connected to an electric battery. One of these electrodes, the 'cathode', gave off an electric discharge when heated by the current, and a stream of 'cathode rays'—as they were called for want of a more accurate name—passed to the 'anode'. The rays themselves were invisible, but the greenish glow of the glass tube walls showed Professor Röntgen that they were being given off.

Crookes had made the experiment, repeated by Röntgen, of putting a metal shield in the form of a small star in the middle of the tube, between the two electrodes, to see if it would cast a shadow. It did indeed; the shadow of the star appeared on the wall of the glass tube. But this did not explain the nature of the rays. Perhaps, wondered Röntgen, perhaps they were ultra-violet rays, invisible light? He put a screen coated with a fluorescent material, potassium platino-cyanide, near the tube. It lit up. Röntgen put the tube in a cardboard box; still the screen lit up, which meant that the rays could not have consisted of ultra-violet light: this cannot penetrate an obstacle such as cardboard. Röntgen reflected: the fluorescent screen showed that these mysterious rays could go through the glass of the tube, the cardboard box, and air. They must therefore be some unknown kind of invisible light. If so—they must cast a shadow. Following a sudden impulse, he held his hand in front of the screen.

He had the shock of his life. For what he saw was not the shadow of his hand, not an ordinary shadow anyway—but a skeleton of a hand! He could see his own bones, with the flesh and skin forming a faint, greyish fringe around them.

One of those accidents which play such an important though freakish part in scientific research had revealed to Röntgen an entirely new kind of radiation. It was able to penetrate thin, solid matter such as flesh and skin, wood and cardboard, metal foil and fabric; but it was stopped by bones and stone, thick

metal and other material of high density. Röntgen also found that the rays affected photographic plates, so that what he had seen on the fluorescent screen could be photographed.

He informed his fellow scientists at once of his discovery by means of a paper, and also made prints of his X-ray photographs available to them. He explained how these rays were produced: when the cathode rays struck a material object such as the star in the tube (the 'target'), they turned into X-rays—rays of a much smaller wavelength than visible light.

Röntgen's discovery caused a popular sensation in those leisurely Victorian days. To think that these rays could make invisible things visible! Smart businessmen advertised 'X-ray-proof underwear—no lady safe without it!', and politicians tabled bills to ban their use. It was only much later that the vital property of the X-rays, their power to destroy organic cells, was discovered; then they began to be used for the treatment of cancer, and everybody handling X-ray apparatus became aware that exposure to these rays could be extremely dangerous.

At the Cavendish there was great excitement about Röntgen's achievement. J.J. got hold of the first X-ray photographs from Würzburg, and Ernest Rutherford repeated Röntgen's experiments. 'You know, one can see the bones of the hand and arm with the naked eye,' he wrote to his mother. 'The method is very simple. A little bulb is exhausted of air and an electrical discharge sent through. The bulb then lights up and looks of a greenish colour. The X-rays are given off and if a piece of cardboard, with a certain chemical on it, is held near it, metal objects placed behind can be seen through several inches of wood.'

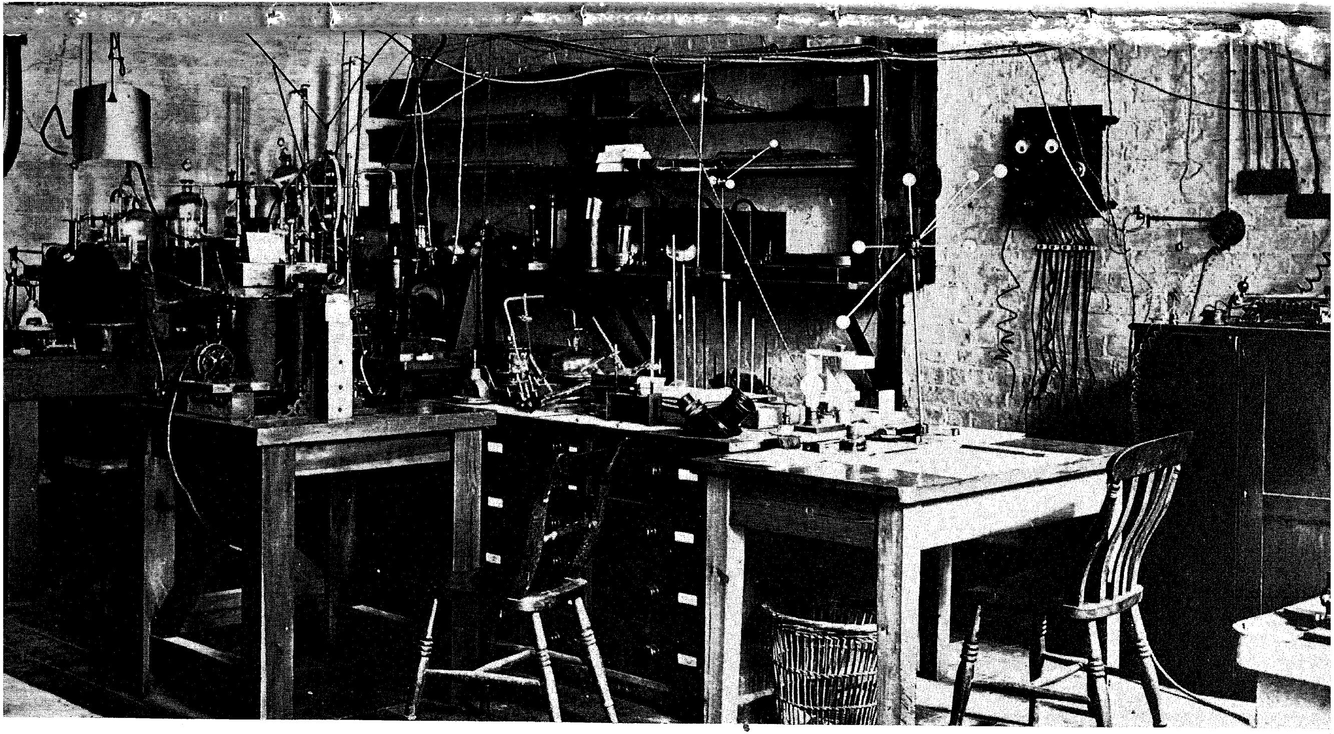
It seems that J.J. was more interested and fascinated by this phenomenon than young Rutherford, who had brought his own research problem with him from New Zealand—a magnetic detector for electromagnetic waves. Following Hertz's demonstration, in 1887, of a method by which these waves could be transmitted and received, experiments were going on in various countries with a view to their use for transmitting

messages. The man who was eventually going to win the race, Guglielmo Marconi, was still a twenty-one-year-old student, carrying out his experiments single-handed at his parents' home in Italy. Rutherford worked on the same lines at the Cavendish. He succeeded in establishing a wireless connection first over a distance of a hundred yards, with three thick walls between, and then over half a mile, 'through solid stone houses all the way'. Early in 1896 he wrote to his fiancée, Mary Newton, in New Zealand:

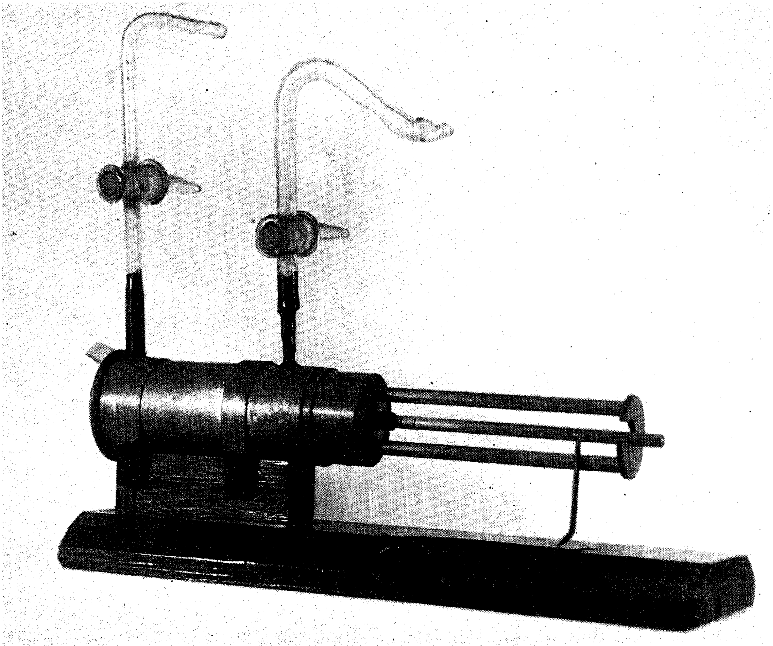
'I have every reason to hope that I may be able to signal miles, without connections, before I have finished. The reason I am so keen on the subject is because of the practical importance. If I could get an appreciable effect at ten miles, I would probably be able to make a considerable amount of money out of it, for it would be of great service to connect lighthouses and lightships to the shore, so that signals could be sent any time. It is only in an embryonic state at present, but if my next weeks' experiments come out as well as I anticipate, I see a chance of making cash rapidly in the future. I cannot say that I am exactly optimistic over the matter, but I have considerable hopes of being able to push it a good long distance.'

Rutherford's emphasis on the financial prospects of his work may sound somewhat unscientific, but he was writing to his girl whom he wanted to marry as soon as he had enough money to do so. In fact, he was in his later career never really interested in financial gain. At that time, however, he seems to have persuaded J.J. to make enquiries as to what the commercial prospects of wireless communication might be, but he was told (one wonders by whom!) that they were negligible. Lord Kelvin, too, thought that something might be made out of it, and tried to get £100,000 for developing the system, but in vain.

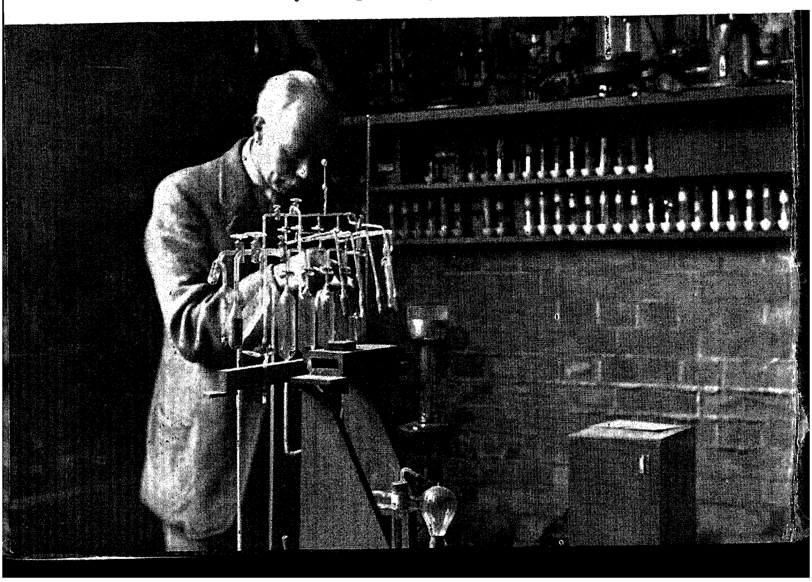
So J.J. suggested to Rutherford to work with him on his own pet subject, the conduction of electricity through gases and in a vacuum, following up Röntgen's discovery. We have seen, at the beginning of this chapter, how J.J. described the line of thought which led him to the discovery of the electron. In an



XI. *Lord Rutherford's laboratory at the Cavendish. This was the room where many of his most dramatic experiments and discoveries were made.*



XII and XIII. (Top) *Rutherford's experimental apparatus. The elementary construction of this device is typical of the simplicity of method at which he always aimed.* (Below) *F. W. Aston in his laboratory. His work on isotopes culminated in their artificial separation for the first time, in 1913.*



article written for the *Philosophical Magazine* in 1897 he explained this in greater detail:

'The experiments discussed in this paper were undertaken in the hope of gaining some information as to the nature of the Cathode Rays. The most diverse opinions are held as to these rays; according to the almost unanimous opinion of German physicists they are due to some process in the aether to which—inasmuch as in a uniform magnetic field their course is circular and not rectilinear—no phenomenon hitherto observed is analogous; another view of these rays is that, so far from being wholly aetherial, they are in fact wholly material, and that they mark the paths of particles of matter charged with negative electricity. It would seem at first sight that it ought not to be difficult to discriminate between views so different, yet experience shows that this is not the case, as amongst physicists who have most deeply studied the subject can be found supporters of either theory. . . .

'The explanation which seems to me to account in the most simple and straightforward manner for the facts is founded on a view of the constitution of the chemical elements which has been favourably entertained by many chemists; this view is that the atoms of the different chemical elements are different aggregations of atoms of the same kind. . . . If, in the very intense electric field in the neighbourhood of the cathode, the molecules of a gas are dissociated and are split up, not into ordinary chemical atoms, but into these primordial atoms, which we shall for brevity call corpuscles; and if these corpuscles are charged with electricity and projected from the cathode by the electric field, they would behave exactly like the cathode rays. . . .

'Thus on this view we have in the cathode rays matter in a new state, a state in which the subdivision of matter is carried very much further than in the ordinary gaseous state; a state in which all matter—that is, matter derived from different sources such as hydrogen, oxygen, etc.—is of one and the same kind; this matter being the substance from which all the chemical elements are built up.'

In these sentences we can see the powerful mind of J.J. at work, groping its way towards an entirely new conception of matter, a revolutionary atomic theory. We must not forget that throughout the nineteenth century the atom was regarded as the basic, indivisible, unchangeable, building brick of nature, and that each chemical element was believed to have its own kind of atoms. But these cathode rays seemed to J.J.—in contrast to the German physicists, who believed them to be some kind of wave phenomenon, similar to visible light—to consist of minute particles, smaller than the smallest atom. He succeeded in measuring the relationship between their mass and their electrical charge. He measured their deflection by magnets; he could bend the cathode rays into a circle of 3½-inch radius. At first he had thought they were electrically charged atoms, but 'my first doubts arose when I measured the deflection of the rays by a magnet, for this was far greater than I could account for by any hypothesis which seemed at all reasonable if the particles had a mass at all approaching that of the hydrogen atom, the smallest then known. . . .'

Throughout the summer of 1897 J.J. was 'bubbling over with enthusiasm over his work on cathode rays', as a Cavendish student put it. He worked with a number of cathode-ray tubes, the largest of them being a 'Braun tube', so called after Professor Ferdinand Braun, an Austrian physicist who had developed it in Strasbourg, a long tube with a large, slightly curved end wall whose inside was coated with fluorescent matter so that it lit up under the impact of the rays. It was the grandfather of our television tube.

Eventually he gave an account of his research to the Cavendish Physical Society, a new 'club' which met every fortnight to discuss recent work. 'Cathode rays,' he said, 'are particles of negative electricity.' And he called them by a name which, although an Irish scientist had coined it six years earlier, now acquired a new meaning: electrons.

IV

The Cloud Chamber

WITH J.J.'s discovery of the electron, the Cavendish began to be regarded as the world's most important research centre dealing with the great question: what is matter? For now there was no doubt that the answer found in the early nineteenth century—the notion of the indivisible, immutable atom—must be wrong. Those among the physicists who were most reluctant to part with it were finally convinced that the question had to be posed and answered again afresh, when news came from France of a discovery no less perturbing than that of Röntgen's X-rays.

Henri Becquerel, one of the leading scientists of that country, experimented with X-ray tubes in an attempt to find out whether fluorescent salts—the kind which Röntgen had used for the coating of his screen—did not give off similar rays. He thought he had found the answer when he noticed that photographic plates wrapped in black paper, on which lumps of uranium ore had been lying for some time, showed traces of light when they were developed, as though some glow-worms had marched across them. He believed that some uranium compounds were producing this radiation and now everybody talked about 'Becquerel rays'. But his assistant, Polish-born Marie Sklodowska, was not satisfied with the Professor's explanation. In 1898, after her marriage to a French scientist, Pierre Curie, she persuaded Baron Rothschild to put at her disposal his disused factory at Nogent-sur-Marne, and asked the administration of the old silver mine at St Joachimsthal in Bohemia to let her have free 10,000 kilograms of uranium pitchblende from the mine; for she had the odd idea that those 'Becquerel rays' were in fact due to some hitherto unknown element distibuted in very small quantities in the uranium.

Marie and Pierre Curie received the pitchblende and boiled it down until they held in their hands a few grains of that new element. It sent out a faint, uncanny kind of light in the dark, and the Curies called it 'radium', the shining element. Its rays, or 'radioactivity', were found to be the emanation of a constant stream of matter and energy consisting of three different types: firstly, what were called alpha rays—in fact, solid particles, obviously fragments of atoms; next, the beta rays, which turned out to be electrons; and third, the gamma rays, which proved to be electromagnetic waves very similar to the X-rays, but of a somewhat shorter wavelength. It was Rutherford who arrived at the startling conclusion that this radiant element was breaking up as it shot out those rays; its atoms were disintegrating and changing into atoms of some other element (in fact, into lead, as it was found later).

Atoms that were breaking up, elements that changed into others almost as the mediaeval alchemists, who hoped to make gold from base metals, had visualized—these were such tremendous revelations that many scientists almost felt the ground under their feet giving way.

There was a strong link between this phenomenon, the X-rays, and J.J.'s pet subject, the electric discharge in gases: ionization. 'Ions', electrically charged atoms or groups of atoms, had been observed for quite some time. Gas is normally non-electric, that is, it does not contain charged carriers of electricity. But when a current is sent through it turns into a conductor of electricity: ions are formed, ionization takes place. The air, like other gases, is normally also a non-conductor; only some strong electric tension, as it occurs in a thunderstorm, makes it a conductor, and then we see the flash of lightning, which is an electrical discharge. The air has become ionized.

X-rays as well as uranium and radium rays were found to ionize the air too. No doubt this result was due to certain movements of the electrons, the negative particles of electricity discovered by J.J.; but what it was precisely was found only later when the true picture of the atom was brought into focus. For the time being, the work on ions promised to lead to

exciting results. Thus, the alpha rays of the uranium and radium were found to be helium ions. 'Ions are such jolly little beggars,' Rutherford used to say, 'you can almost see them!' Of course you could not; and perhaps the most extraordinary feature about the whole of this research work into the secrets of the atom was that it had to be done 'blind', that the scientists could never hope to see the microcosm into which they were penetrating, that their discoveries had to be made by conjecture, theory, calculation, and experiment—comparable to the detective work in some mysterious case in which an unknown, unseen criminal has to be tracked down.

J.J.'s preoccupation with ions was almost a joke at the Cavendish. Songs were composed for the meetings of the Physical Society, to be sung after the meal (with the Professor as guest). One of them, to the melody of 'Clementine', ran thus:

In a dusty lab'ratory
'mid the coils and wax and twine
there the atoms in their glory
ionize and recombine.

CHORUS: Oh my darlings! Oh my darlings!
Oh my darling ions mine!
You are lost and gone for ever
when just once you recombine!

Another 'post-prandial' song called 'The Don of the Day' was set to the tune of 'Father O'Flynn':

All preconceived notions he sets at defiance
By means of some neat and ingenious appliance,
By which he discovers a new law of science
Which no one had ever suspected before.
All the chemists went off into fits;
Some of them thought they were losing their wits,
When quite without warning
(Their theories scorning)
The atoms one morning
He broke into bits.

CHORUS: Here's health to Professor J. J.!
May he hunt ions for many a day,

And take observations,
And work out equations,
And find the relations
Which forces obey.

The research students from overseas took an enthusiastic part in the social as well as in the scientific life at the Cavendish, and on the whole got on very well with the natives. 'The advantage gained by our students from this communion of men of widely different training, points of view, and temperament can, I think, hardly be overestimated,' wrote J.J. later. 'In their discussions they became familiar with the points of view of many different schools of scientific thought, leading to a better, more intelligent, and more sympathetic appreciation of work done in other countries; they gained catholicity of view not merely on scientific but on political and social questions. If the morning paper contained an account of the occurrence of some striking social or political event in our Colonies or abroad, it was generally mentioned when we met for tea in the afternoon, and very frequently we found that there was someone among us from the country where the event happened who was able to throw fresh light upon it and make it seem far more vivid than would the reading of any number of telegrams. I have, for example, when a presidential election was taking place in the United States, listened to Republicans and Democrats fighting their battles over again, and have felt that I learnt far more about American politics by listening to their discussions than by reading columns from special correspondents.'

J.J.'s and Rutherford's collaboration in those years was particularly fruitful, and the first, still vague outlines of a new theory of matter developed from this work. It became clear that the electrons were 'very widely diffused', as J.J. put it, forming a part of every kind of matter and playing an important rôle in many physical phenomena—in short, that there must be electrons in every atom. Unfortunately for the Cavendish, the collaboration between these two great scientists came to an end in 1898 when Rutherford, then only twenty-seven years old, was offered a professorship at the McGill University in

Montreal, Canada. He accepted at once, for this meant more than a step forward in his career—it also meant that he could ask his fiancée to come to Montreal and marry him, which she gladly did.

Rutherford had been offered the post as a result of his research on the 'Becquerel rays'. He had begun to experiment with them even before the Curies had made their discovery known, and found that the alpha rays, consisting of ions, could be stopped by a sheet of thick paper; the beta rays, the electrons, were much more penetrating. When a piece of uranium was placed between the poles of a magnet and over it a photographic plate was held above a slit, two images appeared on the plate—one could see how one kind of ray had been deflected strongly by the magnet while the other kind bent only slightly: their weight must therefore be different. Then there was the third kind, the gamma rays, which went straight on, without being affected by the magnet. This proved that they were not particles of matter but electromagnetic waves. Rutherford continued and expanded these studies and experiments at Montreal; he even ventured to speculate about possible practical uses of the radium rays, and he came to the conclusion—which most of his colleagues thought quite absurd—that one pound of that 'emanation', if it could be caught and utilized, would produce energy at the rate of 10,000 horse-power! He liked scientific 'jokes'. He would, for instance, walk about McGill University with a piece of uranium pitchblende in his pocket, corner the Professor of Geology, and shoot at him the question: 'How old is the earth?'

'Well—according to the latest theories based on geological evidence, one hundred million years.'

Rutherford would then take out his piece of pitchblende and say, 'I *know* that this is seven hundred million years old!'

In 1904, at the age of thirty-three, he published his first book, *Radioactivity*, which won him world fame. Scientists from many countries visited him at Montreal; honours, medals, fellowships of the most distinguished societies were offered to him, but this did not turn his head in the least. He remained the simple,

human farmer's son who would think nothing of taking a broom to clear away the snow in front of his house. He was a voracious reader: the four Montreal lending-libraries could not satisfy his demand for popular history books, biographies, and detective novels.

In 1907 he was offered the post of Professor and Director of the Manchester University Laboratory, which had been founded on the lines of the Cavendish. He was happy to return to England, although Cambridge would have been more to his liking.

But there, J.J. was going as strong as ever. They sang about him at the Cavendish Physical Society:

> My name is J. J. Thomson, and my lab.'s in Free School Lane,
> There's no professor like J. J., my students all maintain.
> I've been here six and twenty years, and here I shall remain,
> For all the boys just worship me at the lab. in Free School Lane!

J.J. had now the help of a most able demonstrator and lecturer, Charles Thomas Rees Wilson, a Scotsman in his early thirties, a man of 'shy but enduring genius', as Blackett called him. At the Cavendish they called him 'Cloud Wilson' because he devoted himself to condensation experiments with ionized air. How did he choose this particular subject of study? 'In September, 1894,' he said later, 'I spent a few weeks in the observatory which then existed on the summit of Ben Nevis, the highest of the Scottish hills. The wonderful optical phenomena shown when the sun shone on the clouds surrounding the hill top, and especially the coloured rings surrounding the sun (coronas) or surrounding the shadow cast by the hill top or observer on mist or cloud (glories) greatly excited my interest, and made me wish to imitate them in the laboratory. . . .'

His work on artificial clouds resulted in the invention of what has been called 'one of the most beautiful and powerful instruments of research', the famous 'Wilson cloud chamber'—a device to make the invisible visible, or at least its tracks. When water vapour is suddenly cooled, for instance by rapidly expanding it, a fine mist is produced; or, to put it in other words,

condensation takes place when the temperature is lowered through a fall in the pressure. Now water vapour condenses on small nuclei such as fine dust or soot in the atmosphere, as those who live in industrialized areas know only too well; the result is fog. It was Wilson's ingenious idea to make ions play the part of these dust or soot particles.

He found that an ion, which is a fast-moving charged particle, ejects electrons from the atoms which it encounters when it passes through such an artificial mist; the result is the production of a large number of ionized atoms which act as nuclei of condensation, and as they shoot through the cloud chamber their tracks—like the trail of a plane exhaust high up in the air—can be seen and photographed. In its simplest form the cloud chamber consists of a metal cylinder with a glass cover at one end; the other is closed by a piston which can be moved up and down to change the pressure. The gas or air between the glass cover and the piston is saturated with water vapour, and a rapid piston movement causes the rapid expansion and cooling of the gas. Precipitation in the form of minute water droplets takes place when ions are formed around an incoming alpha particle. The interior of the cloud chamber is lit up through a side window, and the tracks can then be observed and photographed.

The first model of the cloud chamber, which Wilson made for J.J. in 1911, can still be seen at the Cavendish among the little collection of historical research instruments. He was helped by George Crowe, 'the best-known British laboratory assistant of his time', as he has been called. At the age of fourteen, Crowe, the son of a Cambridge boat-builder, was asked one day to take a message to someone at the Cavendish; as he was delivering it, he was struck by a spark from some machine—and this set off another spark: he decided that this was the place where he would like to work. He went to night school to learn drawing and machine-construction, became a skilled carpenter, and was taught the art of glass-blowing by 'Cloud Wilson', who did all his own glass-blowing. Crowe's first great achievement in instrument-making was the cloud chamber.

He worked with all the famous men who succeeded each other at the Cavendish—for fifty years, until he retired in 1959.

When Crowe started work at the Cavendish, the chief laboratory assistant was Lincoln, a supreme craftsman but a bit of a tyrant who regarded himself as the appointed executive of J.J.'s parsimony. He had entered the service of the Laboratory as a young boy in 1892. If someone required a piece of wood, Lincoln would look at him as if he had asked for the moon. 'We all knew our Lincoln,' says Sir William Lawrence Bragg, who came as a twenty-one-year-old research student in 1911. J. J. had put him on research into the velocity of ions, but he interrupted this work to try to reflect X-rays from crystals—and had the bad luck of breaking a ten-shillings-worth part of a Ruhmkorff induction machine. Lincoln was aghast. He did not buy a new part for many weeks, and research was held up. Young Bragg went on with his X-ray study of crystal structure, which was his own original idea; in 1912 he published his first paper on it—and in 1915, as the youngest scientist ever so honoured, he received the Nobel Prize, together with his father, for his work. And twenty-seven years after his first appearance at the Cavendish, he returned as Sir Lawrence and as the new head of the Laboratory.

For over twenty years, the cloud chamber had more influence on the development of physics than any other piece of apparatus, and a number of most important discoveries have been made with its help. The first of them was made by Wilson himself only a short time after its completion; it was contained in this short but historic statement of his:

'Experiments were now carried out to test whether the production of ions in dustfree air could be explained as being due to radiation from sources outside our atmosphere, possibly radiation like Röntgen rays or like cathode rays, but of enormously greater penetrating power.' A portable electroscope was made, and Wilson took it at night into the Caledonian Railway tunnel near Peebles, Scotland, where he carried out tests—with the same positive results. 'This historic experiment is rightly held to be the beginning of the great and fertile subject

of cosmic rays,' says Professor P. M. S. Blackett, the leading authority in this field of research. Already in 1912 the Austrian physicist, Viktor Hess of Graz, went up in a balloon and proved beyond doubt that these rays did in fact come from outer space—mysterious messengers from the universe, whose origin and nature is still not fully explained.

There is no research institute in the world whose men have collected so many honours and prizes as those of the Cavendish. Lord Rayleigh was awarded the Nobel Prize in 1903, and decided to spend £5,000 of the prize-money on the Laboratory; with this, an extension was built opposite the old building, containing a laboratory, lecture, preparation, and research rooms and a library. It was opened by Rayleigh in 1908. J.J. received his Nobel Prize in 1906, and a knighthood three years later. Rutherford received the Nobel Prize in 1908, was knighted in 1914, and created a peer in 1931. C. T. R. Wilson received the Nobel Prize in 1927 . . . to name only a few items in a list that would be too tedious to recite in full.

Yet we have so far recorded only the early history of the Cavendish: some of the greatest achievements of its scientists were still to come.

V

Portrait of the Atom

'One day in 1911, Rutherford, obviously in the best of spirits, came into my room and told me that he now knew what the atom looked like,' recalled a scientist who was then working at Manchester. The same evening—it was a Sunday—the Rutherfords had some guests for supper at their home, and they received a short lecture on the nature of matter with their roast joint.

Although Rutherford's great achievement, the discovery of the atomic nucleus, was made in Manchester, it was the logical issue of his earlier work done both at the Cavendish and in Montreal.

The portrait of the atom as drawn by Rutherford and a brilliant young student of his, the Dane Niels Bohr, was not, as it has sometimes been suggested, the result of an intuitive flash of genius; nor is it true that Rutherford rushed out into the streets of Manchester in his excitement, crying the English equivalent of 'Eureka!' like Archimedes in the streets of Syracuse. In fact, it was the alpha particles which gave his thoughts that particular direction. Geiger and Marsden—now Sir Ernest Marsden, then a young student—studied the deflection of alpha particles of thin gold foils and solid surfaces and found that a large number were reflected backwards. Rutherford said later that it was as surprising to him as if a 15-inch shell had been reflected from a sheet of tissue paper.

'Rutherford didn't say very much,' said Sir Ernest Marsden later, 'but turned the thing over in his mind.' He talked with Niels Bohr, and some time later 'the penny dropped'. The scientific detectives had tracked their quarry down.

All the known facts fitted, and the behaviour of the alpha

particles made sense if it was assumed that the atom consisted of a central core, or 'nucleus', carrying a positive electric charge, and, revolving around it in various orbits, a number of negatively charged electrons. As the electrons have very little mass—which J.J. had shown—almost the whole mass of the atom must be concentrated in the nucleus. 'Rutherford saw that one could only get forces large enough to deflect an alpha particle through a large angle if the positive electric charge in the atom was concentrated in a very small space,' says Professor Blackett. 'In this way he was led to the very simple and very beautiful theory of the scattering of alpha particles by the nucleus which laid the foundations of, or rather at once established, the nuclear theory of the atom. This was probably the greatest of all Rutherford's great discoveries. Soon after it was made, Niels Bohr welded Rutherford's nuclear atom with Planck's quantum theory of radiation'—that energy emitted by a radiation source was not like a constant stream but was 'parcelled out' in multiples of a fundamental unit, or quantum, of energy, in intermittent bursts—'into the beautiful Bohr model of the electronic structure of the atom.'

But the nucleus, Rutherford explained, is not a single solid piece of matter. It consists of 'protons', each with a positive electric charge equal to the negative one of an electron. Therefore there must be the same number of protons in the nucleus as there are electrons revolving around it like tiny planets around a miniature sun, so that in its normal state the whole atom is electrically neutral. These electrical forces hold the atom together; but if an atom loses one or more electrons, or acquires additional ones, its electrical balance is disturbed—it becomes an ion. Thus X-rays and radium rays ionize the air by knocking electrons off its atoms; the alpha particles turned out to be ions of the gas helium, nuclei without their electrons.

The sizes of the particles with which we are dealing here are infinitesimally small. 'If the entire population of the world were to spend their working day doing nothing else, it would take them fifty years to count a thimble full of atoms,' Rutherford once said, 'and if an atom, the whole little "solar system",

were enlarged to the size of St Paul's, the electrons would be the size of a pin's head.' The protons, however, have about 1,800 times more mass than the electrons. To use someone else's comparison: if we enlarge a whole atom a millionfold it would be as big as a full stop; but if we want to see the nucleus we would have to enlarge the whole atom another 20,000 times until it became as large as a railway waggon—and then the nucleus would be just about visible.

What J.J. had already suspected was confirmed by Rutherford: that the protons and electrons are of exactly the same kind in each element—the only difference being their number (called the 'atomic number'). The lightest element, hydrogen, has one proton, and one electron revolving around it; the heaviest found in nature, uranium, has 92 of each. Rutherford gave many of his fellow scientists 'a rude shock' (as he himself put it) when he said that the mediaeval alchemists had not been so wrong after all: that the transformation of one element into another—by the removal or addition of protons—was not only taking place in nature all the time but might one day even be achieved artificially, and energy might be liberated in the process. 'There is no doubt,' he said, 'that the atom is the seat of an intense electric field.' But he also warned (was it meant seriously, or was it one of his scientific jokes?) that 'some fool in a laboratory might blow up the universe unawares'.

He did not then assume that the electron and the proton were the only kinds of particles to be found in the atom. But it took another twenty years before another important particle, the neutron, whose existence Rutherford had strongly suspected, was discovered.

At Montreal, Rutherford had joined forces with Frederick Soddy from Oxford, who was still in his early twenties. Their association lasted no more than two years, but its effect on the course of atomic research was enormous. Together they investigated the element thorium which, like uranium, is radioactive; they studied its disintegration and radiation, and as Soddy continued this work alone he made an astonishing discovery—all the more surprising because its author was then

only twenty-three years old. He identified, and named, the 'isotope'. He found that some elements—in fact, as it turned out later, most elements in nature—really exist in two or more varieties, identical in all their chemical and most of their physical properties and with the same atomic number (that is, the same number of protons and electrons), but different in atomic weight. He called the variations isotopes (from the Greek *isos*, the same, and *topos*, place), i.e. occupying the same place in the table of chemical elements. Soddy, investigating the problem of what made the uranium give off rays, found that 'ordinary' uranium, atomic weight 238, was always mixed with small quantities of a lighter variety, atomic weight 235, which was in a very 'unstable' state: like radium, it was breaking up, giving off the radiation which Professor Becquerel had first observed on his photographic plates. Soddy could not have foreseen that his discovery, the uranium isotope, would one day change the face of the earth. Nor could he anticipate that he would see, at the end of his life (he died in 1956), how the heavy isotope of hydrogen was being used for the most terrible weapon mankind has ever known.

In the meantime, at the Cavendish, Professor Thomson had taken up the study of the 'positive' or 'atomic' rays coming from the anode in a cathode-ray tube. He examined them by making little holes, or channels, in the cathode of the tube, and reducing the pressure in it substantially. Then rays with a luminous track could be seen streaming through the holes into the space behind the cathode. These rays were rather different from the cathode rays. They produced a different colour in the gas along their path, a different kind of phosphorescence of the glass walls, and—their most important characteristic—they were unaffected by magnetic deflection unless the magnet was very powerful. When they did react to such a magnet their deflection was the opposite of that for cathode rays, which proved that they consisted of positively charged particles. They moved on like bullets after leaving the muzzle of a gun, and complicated processes were going on when they shot into the space behind the cathode.

At the Cavendish Physical Society evenings they were singing:

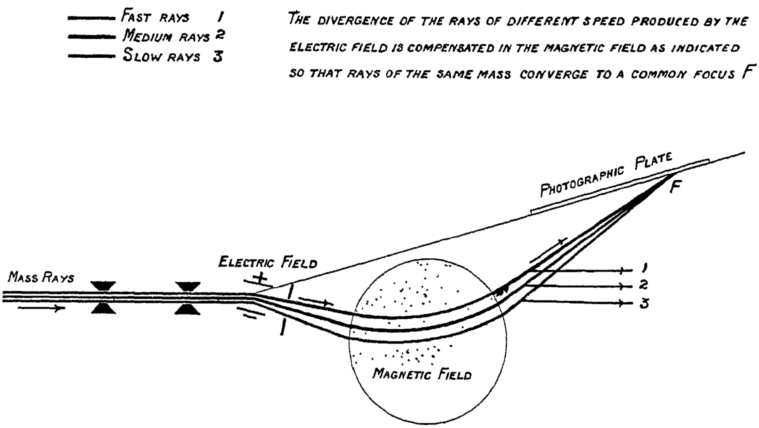
Our worthy professor is always devising
Some scheme that is startling, new and surprising
In order to settle some question arising
On ions and why they behave as they do.
Thus, when he wants to conclusively show,
Some travel quickly and some travel slow
He brings into action
Magnetic attraction
And gets a deflection
Above or below!

J.J. was helped by some quite outstanding men. There was G. F. C. Searle, a lecturer with great enthusiasm for teaching and a genius for devising experiments, as well as with sincere personal interest in his students. He had begun his fifty-five-year-long association with the Cavendish in the 1880's as an assistant demonstrator, and there are still in existence at the Laboratory his hand-written 'Useful Rules' which end with the plea to students: 'Demonstrators are only human. They need your sympathy and your prayers as much as other men.'

Then there was Francis William Aston, who had started his career as a research chemist in a brewery around the turn of the century. In 1910 he came to the Cavendish to work under J.J., who asked him to help him with his positive-ray research and his experiments with the rare gas neon, which was found to contain two isotopes. There is among the collection of historical apparatus at the Cavendish a famous piece of equipment which bears witness to the genius of Aston: a model of his mass spectroscope.

Since there was no chemical way of separating the isotope of an element from its ordinary variety (at least not yet), Aston split them by passing them through a magnetic field. At first, his mass spectroscope, or spectrograph, was only meant to identify the two varieties of an element, but in 1913 he actually

succeeded in separating them with it. The system has been compared with two racing cars of different weight crossing the starting line together and shooting along the straight track until they come to the turn—the curvature produced by magnetic deflection. Here, the lighter car would drive along the inner rail while the heavier car would be forced to describe a wider curve: the two cars would separate. In Aston's apparatus the 'cars' were atoms of different weight, which he forced into two different paths; thus he achieved the first artificial separation of isotopes.



The principle of the mass spectrograph

It was during J.J.'s and Aston's collaboration on positive rays that there gradually dawned on them what even Soddy had not suspected: that not just a few, but most elements consisted, in fact, of a mixture of 'ordinary' and isotope atoms; that some elements even had a number of isotopes (there are, for instance, two kinds of heavy hydrogen, today known as deuterium and tritium, and several varieties of uranium). These discoveries, however, did not yet explain the reason for such differences in

weight, but they led the physicists gradually towards the assumption that there must be some hitherto unknown, neutral particle in the nucleus.

The war of 1914 marked the end of this period of research at the Cavendish; in fact, it marked the end of a whole era of scientific work. Not only because the normal activities of the Laboratory almost ceased, most of the workshops were turned over to making military equipment, and the students joined up; not only because some of them—like that brilliant Manchester physicist, Henry Mosely, who fell at Gallipoli—lost their lives; but because the whole atmosphere of scientific study and experiment underwent a change more fundamental than anyone could have realized at the time. As Professor Andrade has put it, that pre-war period of research was 'so remote from the spirit of our present times that it seems another age. . . . The universities ceased to be places where it was possible to find the undisturbed time to think, which is a condition for great discoveries.'

However, it was not yet the end of the 'string-and-sealing-wax' period of experimenting, when important work could be done with simple, home-made apparatus. J.J., although he continued to lecture to the Laboratory classes which had dwindled to very small numbers, gave much of his time to the Board of Invention and Research, a Government agency set up by the Admiralty to assist the war effort. Women students and medical students were the main contingents at the Cavendish between 1915 and 1919; there seemed to be little understanding of the need for training young scientists. They were more urgently required in the trenches of France. The workshops were busy making precision gauges. Soldiers were billeted at the Laboratory.

Early in 1918, J.J. accepted the mastership of Trinity College. 'I do not expect that the Mastership will diminish the time that I can give to science. I am determined that it shall not,' he wrote to his son. But he had to discover that his new responsibilities made it impossible for him to direct the affairs of the Cavendish, which looked like growing into an even

larger institution after the war; so he resigned his professorship in 1919, but continued as an unpaid professor and frequent visitor at the Laboratory, carrying out some scientific work there, taking an interest in the students, and keeping up his friendship with his one-time 'young man' who was elected to succeed him—Sir Ernest Rutherford.

VI

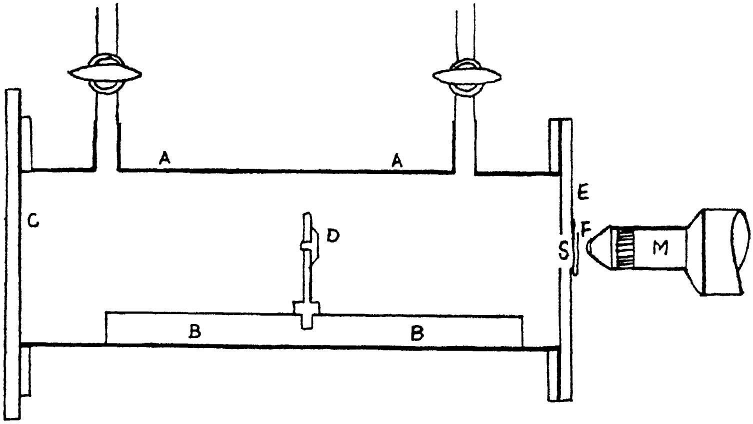
'The Atom has been Split'

'THE experiments started about four in the afternoon,' recalled a scientist whom Rutherford had invited to the Cavendish one day in 1919 to see what he was doing. 'We went into his laboratory to spend a preliminary half hour in the dark to get our eyes into the sensitive state necessary for counting. Sitting there, drinking tea, in the dim light of the minute gas jet at the further end of the laboratory, we listened to Rutherford talking of all things under the sun. It was curiously intimate yet impersonal, and all of it coloured by that characteristic of his of considering statements independently of the person who put them forward.' Then Rutherford made a last-minute inspection tour.

A small source of radium provided a stream of alph particles, which shot into a tube full of nitrogen gas. Towards the end of the tube was a screen covered with zinc-sulphide crystals. This chemical produces faint sparks when it is hit by atomic particles. The tube had an inlet valve for nitrogen gas. The whole apparatus lived in a small brass box, and the flashes which intermittently appeared on the screen had to be observed through a microscope.

'You know, we might go up through the roof,' warned Rutherford, but the boyish chuckle belied his words. He bent over the microscope. There was a minute of silence. Then he turned to his guests. 'You can see particles from the disintegration of nitrogen.'

Now it was the visitors' turn to watch the faint sparks on the screen, which appeared at irregular intervals. What was happening? Millions and millions of alpha particles—helium nuclei—went through the nitrogen gas in the tube without touching any of its atoms; but now and then one scored a hit



Radium, the source of alpha rays, is deposited on the face of a disc D, which is itself mounted on the slide BB. The whole is enclosed in the box AA, which can be exhausted or filled with a suitable gas. *E* is the end of the box in which is cut an opening covered by thin silver foil. The zinc-sulphide screen is placed at *F*, 2 mm. from the window (further absorbing screens are placed between the window and the zinc-sulphide screen). The apparatus placed in a strong magnetic field in order to bend away the beta rays, which otherwise would cause strong luminosity of the zinc-sulphide screen. *M* is the microscope through which flashes on the screen are observed.

Rutherford's experimental arrangement for investigating collisions of alpha particles with light atoms

on a nitrogen nucleus, breaking it up so that one or two of the seven protons shot out from it, forming one-proton nuclei of hydrogen. 'It is difficult to avoid the conclusion that the long-range atoms arising from collision of alpha particles with nitrogen are not nitrogen atoms, but probably atoms of hydrogen or atoms of mass 2,' wrote Rutherford in a paper published in the summer of 1919, describing experiments carried out in Manchester during the war years. 'If this be the case, we must conclude that the nitrogen atom is disintegrated under the intense forces developed in a close collision with a swift alpha particle, and that the hydrogen atom which is liberated formed a constituent part of the nitrogen nucleus.'

Thus Rutherford had not only for the first time achieved an artificial disintegration of the atomic nucleus, but had in fact

transmuted one element into another. 'Thus was born the vast modern subject of nuclear physics,' wrote Blackett, 'which now gives such fertile research problems to so many of the world's physicists and, incidentally, such headaches to so many of the world's statesmen.'

Rutherford's little laboratory experiment created tremendous excitement among the physicists, and the popular press carried sensational stories about 'atom-smashing'. But perhaps only Rutherford understood its full meaning. He came to the conclusion that the energy which made the disintegrated parts of the nitrogen nucleus fly off must have come from the nucleus itself—some of its mass must have changed into energy! If the two particles which had flown off after such a collision could have been put together again, a tiny fraction of matter would have been missing from the nucleus, the piece that had become pure energy. Already in 1905, Albert Einstein, in his 'Special Theory of Relativity', had given the phenomenon of radioactivity an important place within the framework of his new picture of the universe. He predicted that if matter could be converted into energy, that process would take place according to the equation $E = mc^2$.

What did he mean? Basically, he explained, mass and energy are not, as it had been assumed throughout the ages, different things which have no relation to one another—the one can be changed into the other. Einstein's equation connects the two quantities. 'E' is the energy in ergs released when a mass of 'm' grams is completely disintegrated; 'c' is the velocity of light in centimetres per second (30,000 million) and therefore c^2 is 900 million million million ergs.

This sounded completely fantastic. Even if matter could ever be converted into energy, argued the scientists, surely the energy released in this process would not be of such unimaginable magnitude! There was, of course, no way of proving or disproving Einstein's equation—until Rutherford showed how to split the atom.

As soon as Rutherford had settled at the Cavendish he collected around him a team of young workers whom he used to

call 'the boys'. 'His own keenness and enthusiasm was infectious', wrote one of them, Dr Alexander Wood, 'and he devoted himself to securing for "the boys" the necessary material resources in the way of endowments, accommodation, and apparatus. J. Chadwick had come with him from Manchester, and among others who did distinguished work at the Cavendish at this period must be mentioned . . . P. M. S. Blackett, J. D. Cockcroft, M. L. E. Oliphant, E. T. S. Walton. . . .'

Rutherford's personal assistant who built and set up his apparatus was George Crowe, who had returned from the war. Rutherford was Crowe's undisputed hero. 'He was jolly, humane, but he had no use for anyone who did not work—no use at all,' recalls Crowe. But this loyal laboratory assistant paid dearly for the great satisfaction he felt in helping the famous professors. In the early days of X-rays and radium the risks in handling the equipment and materials were not yet fully understood, and Crowe suffered considerably over the years; he lost a finger and some of his hearing, and he had to undergo a number of skin-grafting operations. He took it all with much cheerfulness.

At the Physical Society they had now a Rutherford song:

> What's in an atom the innermost substratum?
> That's the problem he is working at today.
> He lately did discover how to shoot them down like plover,
> And the poor little things can't get away.
> He uses as munitions on his hunting expeditions
> Alpha particles, which out of radium spring.
> It's really most surprising and it needed some devising
> How to shoot down an atom on the wing!

F. W. Aston, who had worked at Farnborough on aeroplane fabrics during the war, returned to the Cavendish, and perfected his mass spectrograph by inventing a focusing method by which he succeeded in determining the principal isotopes of most gases and other elements which could be introduced into a gas discharge. This enabled the chemists to review their determinations of atomic weights.

Shimizu had to return to Japan rather suddenly in 1921, and

Rutherford asked the twenty-four-year-old, newly graduated student of physics, P. M. S. Blackett, to continue the work—'which I, of course, was most excited to do,' Blackett recalls. 'He set me the problem of attempting to use C. T. R. Wilson's beautiful cloud chamber method to photograph the disintegration of nitrogen nuclei, which he had observed by means of scintillations. This meant making an automatic cloud chamber which would take a very large number of photographs. I made use of many parts of Shimizu's original apparatus and his camera design. After three years' preliminary work mainly concerned with the development of an automatic cloud chamber, I succeeded in 1924 in taking within a few months some 25,000 photographs showing the tracks of 400,000 alpha particles, and amongst these tracks I found six which clearly represented the process of atomic disintegration discovered previously by Rutherford. I studied in detail the frequent forked tracks formed when an alpha particle collides with the nucleus of an atom of the gas, and showed by accurate measurements of the angles of the fork that the collisions were inelastic. . . . The novel result deduced from these photographs was that the alpha particle was itself captured by the nitrogen nucleus with the ejection of a hydrogen atom, so producing a new and then unknown isotope of oxygen. The apparatus was made completely automatic and, when things went well, it was possible to take 1,000 photographs a day giving tracks of some 20,000 alpha particles. Thus the problem set four years before by Rutherford of what happens to the alpha particle on disruption of a nitrogen nucleus was solved.'

Each of the photographed tracks was studied for unusual features, and a small number of them were found to show quite a different appearance from those indicating 'normal' elastic collisions between alpha particles and nitrogen atoms. They were identified as photographs of transmutations of nitrogen. An ordinary collision would show a forked track with three 'branches': the alpha particle, the ejected proton, and the recoiling nucleus. But occasionally there were only two tracks—that of the proton and a heavy one which turned out to be of a

heavy oxygen nucleus, atomic weight 17 (ordinary A.W., 16). The formula for this transmutation was therefore:

$$He_4 + N_{14} \rightarrow H_1 + O_{17}$$

The heavy oxygen nucleus was an isotope, but at the time this was not yet known. In fact, a true transmutation of elements had taken place, and the experiments which followed these discoveries 'gave for the first time detailed knowledge of what is now known to be a typical nuclear transformation process', as Blackett wrote.

Blackett's first automatic cloud chamber was extremely small, of only 6 centimetres diameter and 1 centimetre depth. His second model was much larger, with a diameter of 16 centimetres; with this he succeeded in photographing 1,100,000 tracks, but only four of them showed a transmutation. Soon, however, Blackett's sphere of interest shifted considerably.

We know that Wilson himself had first discovered tracks of particles which seemed to have got into his cloud chamber from outer space, and that subsequently a number of scientists went up in balloons to study what began to be called cosmic rays. In 1927, the Russian physicist, Skobeltzyn, had found on his photographs cosmic-ray tracks of great energy.

Blackett and his Italian colleague G. P. S. Occhialini started work in 1931 on the problem of making cosmic-ray particles take their own photographs, by combining Geiger counters with a specially constructed cloud chamber. The first photographs by the new counter-controlled cloud chamber were obtained in the spring of 1932. In the summer of the same year, Karl Anderson of the California Institute of Technology found convincing evidence of the existence of positive electrons among the cosmic rays.

Within another few months, Blackett and Occhialini had confirmed this discovery by photographing showers of cosmic-ray particles, finding half of them positively and half negatively charged. They concluded that these positive and negative electrons were born in pairs when energetic cosmic-ray particles collided with atomic nuclei, and that their process of

creation and the subsequent annihilation of the positive electrons could be accurately described by Dirac's famous theory of the 'relativistic electron', with its concept of 'holes'. The energy taken to produce such an electron pair is about one million electron volts, as given by Einstein's famous relation $E = mc^2$.

It was not generally known that Blackett also played an interesting part in the early development of radar techniques until Sir Robert Watson-Watt recalled the fact in his autobiographical book *Three Steps to Victory*. 'The first time I heard the suggestion that high-frequency direction-finding should be tried on shore and in ships to locate the individual and talkative U-boats, was from Professor P. M. S. Blackett,' Sir Robert wrote. 'Patrick Blackett had been such a good young naval officer in the first World War that the Admiralty sent him to Cambridge—thus setting him on the road that led to a Nobel Prize in Physics.'

Although he has designed and used some of the most intricate scientific apparatus, Blackett believes that a researcher should 'always remember that complication is not an end in itself but a means to an end'. One of his favourite stories is about a young research worker in a Defence laboratory where some complicated electronic instrument for sighting a gun was being designed, who went up one morning excitedly to his superior and said, 'Sir, I have made a discovery. If you take a rod and rest its centre on a solid support, then if you press one end down, the other end goes up. This will save six valves!' Rutherford, says Blackett, would greatly have appreciated this story.

Blackett has drawn a fascinating picture of Rutherford the scientist, and tried to analyse 'some of the secrets of his success'. He lists these as follows: 'Rutherford's extreme power of concentration on a particular problem until he could see it from all sides and from all angles; his vivid pictorial imagination in space and time of the events of the world of subatomic particles, which was his favourite field of investigation; his gift for designing simple apparatus perfectly suited to the job in hand; his

flair for spotting and following up rewarding lines of research; his eye for the unexpected; his sparing use of mathematics but his great success with it when he did; and lastly his boundless enthusiasm for finding out more about the physical world.'

Rutherford himself, however, had quite a different formula for scientific success. It was: 'Never attempt a difficult problem!' To us it seems that few scientists ever attempted more difficult problems than Rutherford; but then, it all depends what you regard as difficult. What Rutherford meant was: don't waste your time on insoluble problems. But it often needs a brain like his to sense beforehand whether a problem can be solved or not.

Professor J. D. Bernal, who was at the Cavendish as a student from 1919 to 1923 (and was to return later as a lecturer), found Rutherford terribly dull in the lecture room, but all the more fascinating as a speaker at meetings in which he was reporting on the work of his collaborators. 'Blackett, too, seemed to be two different people,' says Bernal. 'One is still the naval officer who fought in the battle of Jutland as a midshipman, who thinks the only people worth talking to are the generals and admirals, and the other is Blackett the brilliant scientist, the ingenious experimenter, a real leader in research.' He also had a 'knack of inventing devices', as Ritchie Calder says.

Even under Rutherford, the string-and-sealing-wax period in the 'nursery of genius' lingered on. 'It was a nursery in which infant "genius" was given its fling,' says Calder. 'It was in the best Montessori tradition; the "infants" were encouraged to use their hands as well as their heads and to "make do and mend" . . . I recall an incident in the thirties. Escorted by Rutherford, an eminent American and I were being taken round the Cavendish. In a murky corner, a shadowy figure was solemnly turning the pedal of an upturned bicycle. The rear wheel had been removed and the chain was driving some sort of dynamo. As we passed the shadow hailed us, "By the way, Prof., when do I get that motor?" Rutherford heartily assured him, "Any day now! I think I can raise the money and place an order. Any day. . . ." Later, as an afterthought, he said, "Of course

you know who that was? That was Aston, the Nobel Prize-winner. . . ." ' We have to take Professor Calder's word for the truth of that amazing story!

Bernal was wondering whether he should go in for crystallography, which interested him, or for nuclear physics, which seemed to be the great fashion among young scientists. But Bernal thought it would 'lead nowhere'. So he became a crystallographer, and wrote a thesis on the crystal structure of proteins, the subject in which he was to achieve his greatest scientific success. He was a lecturer and later Assistant Director of Research in Crystallography at the Cavendish from 1934 to 1937.

For those fortunate enough to be students or research workers at the Cavendish, the twenties and thirties were a most exciting period. The 'Cavendish tradition', says Calder, 'broke down the isolationism of research. . . . It was a case of taking the informality of the common-room into the laboratory, retaining, and, indeed, encouraging the individuality of the scientist however junior, and making the professor the mentor rather than the master of research. At the same time, it was what we might call today a "working-party" in which everyone swopped ideas and, when necessary, lent a hand with the other's chores.'

VII

Kapitza and his Club

IN 1921, while all Russia was still in the throes of violent revolution and civil war, a young Russian, son of a Tsarist general, came straight from the Leningrad Polytechnic to the Cavendish and presented himself, a cloth cap on his head, as a research student. Rutherford liked him from the first moment.

Peter Kapitza was indeed a remarkable young man—mentally immensely alert, amusing, eccentric, with an incredible zest for work, and great endurance. During his fourteen years at the Cavendish he was next to 'the Prof.' the dominating figure. It was even said that he had Rutherford 'completely under his thumb'. In the art of getting money for research he exceeded his master by far.

He would race his fast sports car at top speed over the country roads, bathe in the nude in the Cam and frighten the swans with his imitation of a bird's alarm cries, and burn up copper coils in producing very strong magnetic fields. 'Find out what other scientists are doing,' was his motto, 'then exceed their bounds, and see what happens!' Kapitza experimented with alpha particles in these magnetic fields and he studied the conductivity of metals by subjecting them to extremely low temperatures when molecular movement slows down almost to a standstill.

Practical jokes were Kapitza's special line. Once he presented himself to the press photographers during a conference of physicists at Zürich by lying in front of the wheels of a motor-car. 'I always wanted to know what I look like being run over,' he explained. 'He's a card,' grinned Rutherford. It was at his suggestion that the Royal Society gave Kapitza a professorship.

Once a month the 'Kapitza Club'—with Kapitza himself, Cockcroft, Blackett, Dirac and Mark Oliphant as its core of 'members'—met in Cockcroft's room. 'Attendance was compulsory,' said Bernal, who returned to Cambridge in 1927. 'If you missed two sessions running you were thrown out. It was a kind of grand inquisition on all the important questions of physics. Men with great names were 'summoned', heckled, and interrupted; Kapitza did most of the heckling, but no one minded it because of his enthusiasm.'

Rutherford decided that Kapitza must have his own laboratory for magnetic-field and low-temperature research. The Royal Society had a considerable sum of money bequeathed by Ludwig Mond, the millionaire chemist and co-founder of the I.C.I. The Royal Society gave £15,000 for the building of what was to be called the Mond Laboratory. Kapitza was most excited about the prospect of working in it. Before it was opened early in 1933, a sheet of canvas had been hanging for some time half-way up the outer wall, near the entrance door. Kapitza did the 'unveiling' when everybody at the Cavendish, with Rutherford in the front row, attended the opening ceremony. The canvas had concealed a beautifully carved crocodile in the façade. Kapitza had paid for it out of his own pocket; it was the work of Eric Gill, the famous sculptor, who had among many other things created the figures at London's Broadcasting House.

The University people were puzzled. Kapitza explained: 'In Russia the crocodile is the symbol for the father of the family. But this animal is also regarded with awe and admiration because it has a stiff neck and never turns its head. It just goes straight forward—like science, like Rutherford.'

Those in the know chuckled. Everyone knew that Kapitza used to call Rutherford 'the old crocodile'. He even had a crocodile as his mascot on the bonnet of his Lagonda car.

It was one of Kapitza's last practical jokes. In the summer of 1933 he went with Bernal to a scientific conference in Russia. They both returned without a hitch. The year after, Kapitza went alone. He never returned. He was told by the Soviet

authorities that he was still regarded as a Soviet citizen, and that in view of the rise of Hitler's power in Germany and the increasingly dangerous world situation they could no longer dispense with his services.

It was a great shock to Rutherford and everyone at the Cavendish. Rutherford wrote at once to Moscow, asking them to release Kapitza. The answer was that the Soviet authorities understood well enough that England would like him back; but his country needed him. So Rutherford asked only that Kapitza should be given, in the interests of science, the facilities and the scope which his genius deserved. The Russians did this; they built a special institute for him, and at Rutherford's request the University of Cambridge arranged to transport to Moscow much of the apparatus which Kapitza had been using, so that he could carry on his research work. Two of his assistants were given leave to go with the apparatus, help with its installation in Kapitza's new laboratory, and instruct his helpers in its use. In return, the Soviet authorities provided the Cavendish with funds to re-equip the Mond Laboratory for other work. This helped the Mond to make a good recovery; valuable work was done on the properties of liquid helium at very low temperatures—in 1937, a temperature within 0·005 of a degree of absolute zero was reached.

'And so Kapitza became a legendary figure in the world of science,' says Ritchie Calder. 'When the Americans claimed the monopoly of the "know-how" of the atomic bomb, there were those who said, "But what about Kapitza?" Always during the uneasy post-bomb period, it was an eternal query, "What is Kapitza up to?" The disciple of so great a master as Rutherford could not be inactive.' We now know that he was working on low-temperature problems and not on the atomic bomb.

At the Cavendish, the Club continued until 1957, surviving for two decades the great 'nuclear period' of research—a period which brought the climax of the Cavendish's inter-war achievements under Rutherford's guidance.

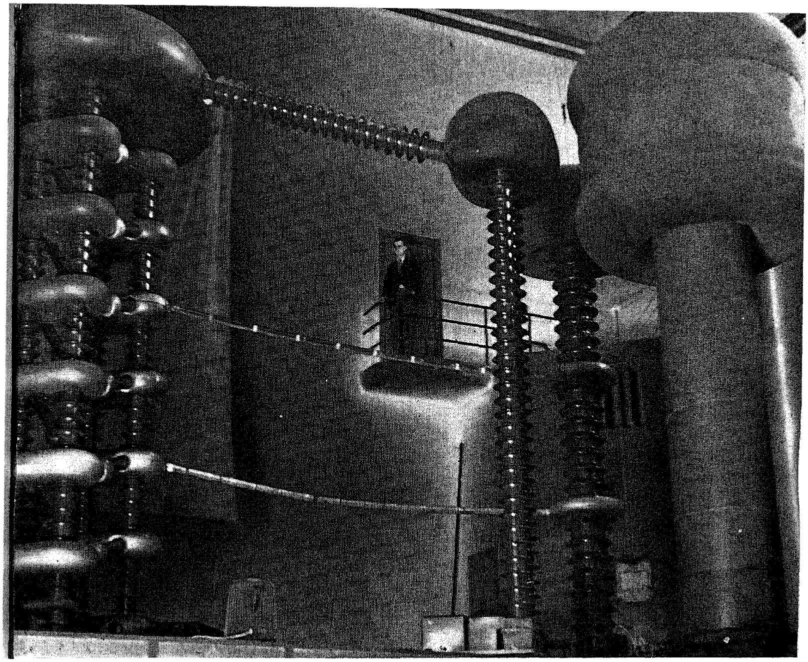
A newspaperman gave a most vivid description of him in those years. He appeared to him like 'a hearty farmer who's

enjoying his breakfast.... His healthy colour, blunt features, shrewd eyes, heavy limbs, and even his easy tweeds, with their baggy pockets, all seemed aggressively agricultural.... Sir Ernest Rutherford wears his laurels lightly. His fellow-workers, from his senior assistant to the junior "lab-boy" who is privileged to empty his waste-paper basket, adore him. His smile is perennial, his kindly good humour inexhaustible. Other men may lose their tempers, or their heads, or their courage. Sir Ernest is the same yesterday, today, and—apparently—for-ever!'

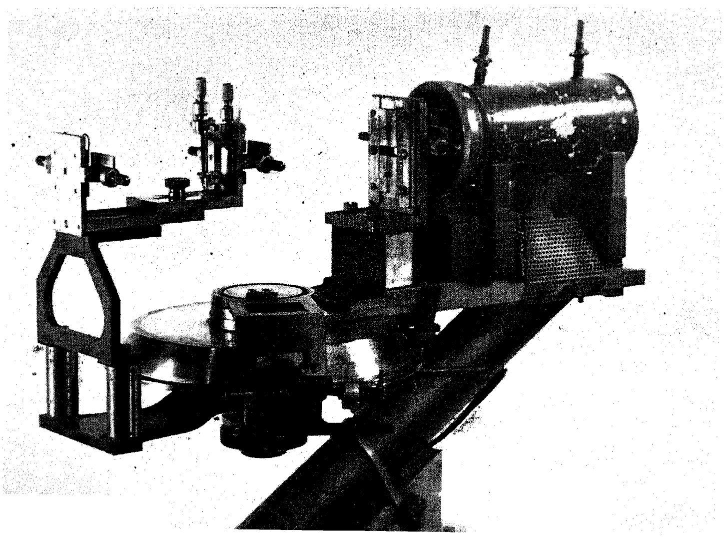
But after 1931 he was no longer 'Sir Ernest'. The New Year's honours brought him the supreme acknowledgment of his achievements. He was created a baron, and chose the title of 'Lord Rutherford of Nelson', thus linking his name with that of the New Zealand town where he was born and where he went to school.

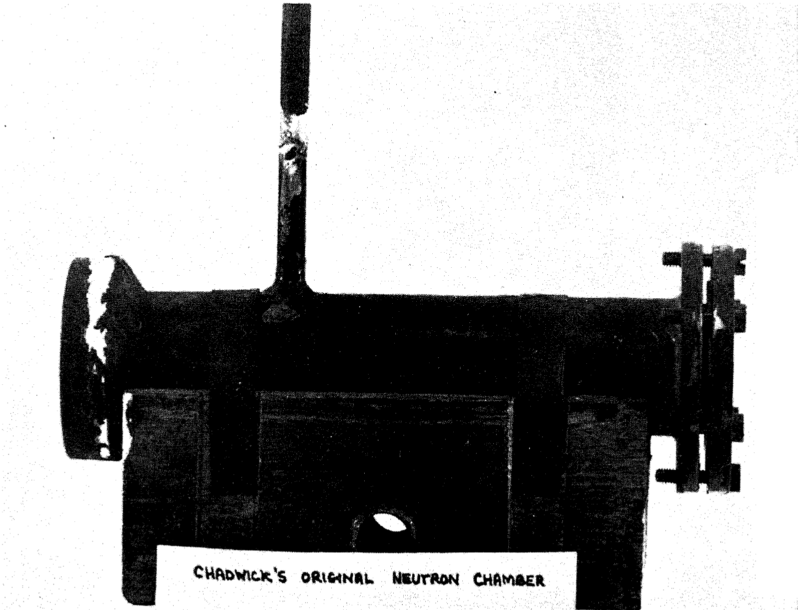
'Rutherford is very likely the major scientific figure since Newton,' said Sir Charles Snow (C. P. Snow, as this scientist calls himself as a writer), in his reminiscences of the Cavendish in the early thirties. 'He was larger than life. He revelled in creation and success and everything that happened to him. He used to tell us so in a loud voice and an antipodean accent. I never heard a voice quite like that anywhere else. It was to this man we owe the entire atomic age. And the Cavendish was the greatest physics laboratory in the world.'

J. J. was still about, shuffling through the rooms, with his hands clasped behind his back. He lectured on electrical discharge in gases. Crowe, the laboratory assistant, remembers how the old man would become fascinated by some particular problem; at one time it was the flight of golf balls, and as he walked absent-mindedly through the Laboratory, he was throwing and spinning imaginary balls.

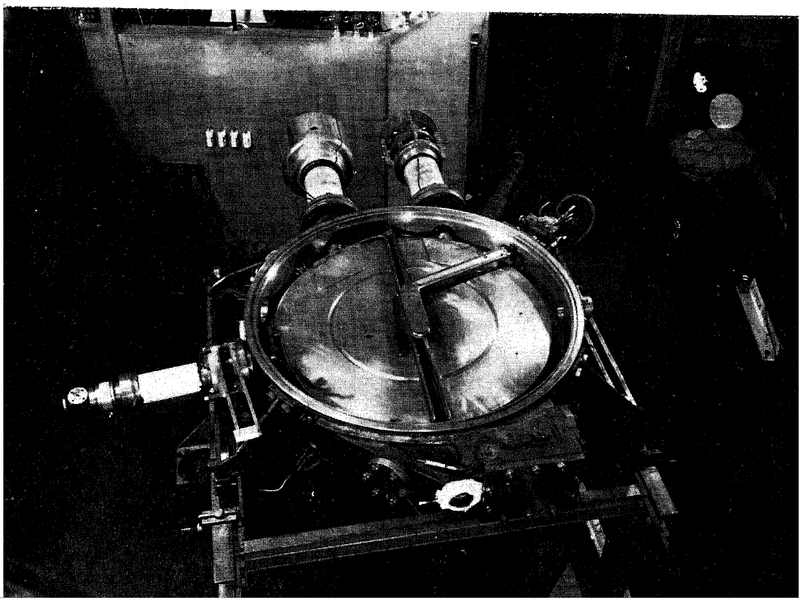


XIV and XV. (Top) *The high-tension laboratory at the Cavendish before the second world war.* (Below) *Sir Lawrence Bragg's X-ray spectrometer, used in the study of crystal structure for which he, with his father, received the Nobel Prize. He returned to the Cavendish as its head from 1938 to 1953.*





XVI and XVII. (Top) *The apparatus used by James Chadwick for the discovery of the neutron, which he announced in 1932.* (Below) *An early cyclotron installed at the Cavendish in 1939, used to accelerate particles for bombarding the nuclei of atoms.*



VIII

The Discovery of the Neutron

SCIENTIFIC discovery is very often like a football match. The players kick the leather around until the time comes to drive it forward; it passes from one player to the other (in fact, they may be separated by oceans and continents), until one of them scores a goal. He could not have done it without the preparatory work of the other players. The football fans who watch the game know this very well and follow the kicking-around of the ball with mounting tension and expectation. In scientific life, even the experts rarely know where the game might lead to—whether a goal can be scored at all, or whether the problem they are working on will prove too difficult for solution . . . as yet.

The discovery of the neutron, which proved to be one of the achievements leading directly to the utilization of atomic energy, is one of the comparatively rare cases in which the 'kicking-around' of the ball can be retraced with great accuracy. We know that Soddy had found, before the first world war, that chemical elements can have 'twins', similar in most respects to the ordinary variety but of greater or smaller mass (or weight). In 1920, Rutherford made his famous speculations on the possible existence of an electrically neutral particle, which he visualized as a close combination of a positively charged proton and a negatively charged electron so that the whole particle would have no electrical charge. He said that if such a particle existed it would be able to move freely through matter, being neither repelled nor attracted by other particles. In 1924, James Chadwick, who was in general charge of research at the Cavendish under Rutherford, began to 'look for it' by making a series of experiments. He has said that he came close to its discovery a few times.

Already before the first world war he had worked, as one of Rutherford's 'young men', at Manchester, and made friends with a German physicist, Hans Geiger, the inventor of the famous Geiger counter. In 1913 he went with Geiger to Germany and was interned as an enemy alien when war broke out; Geiger managed to get him some scientific equipment into the camp so that Chadwick was able to do some research work. It led, a decade and a half later, to the discovery of the neutron.

The solution of the problem came only after a number of observations had been made in different countries. In Germany, the physicists Bothe and Becker found that when alpha particles from the radioactive element polonium (discovered by Marie and Pierre Curie) fell on the light metal, beryllium, hard gamma rays were produced—or so they thought. When Bothe disclosed his findings at an international congress of physicists in 1931 there was a good deal of speculation about the phenomenon. Several scientists in their turn repeated the experiment.

In France, Frédéric Joliot-Curie and his wife Irène, Marie Curie's daughter, studied the beryllium rays with a cloud chamber, and let them hit a paraffin 'target'. To their great surprise they found that some protons of a very fast-moving kind were produced. Obviously, that radiation was setting light nuclei in violent motion. In January 1932, they published their results in a French scientific journal.

At the Cavendish, James Chadwick read the French scientists' account, and recognized in a flash that this must be the neutral particle whose existence Rutherford had postulated a long time ago. Those beryllium rays could never be gamma rays—they must be streams of hitherto unknown particles which leave no trace in the cloud chamber because they have no electrical charge; particles with the mass of a proton. No doubt they were fundamental building bricks of matter. They must be the reason why there are atoms of the same element with more or less weight: the chemical elements all seemed to have such particles in their nuclei, and the isotopes of an element must have more or fewer of them than the ordinary variety, which would account for their different weights.

Chadwick built a very small, but extremely efficient chamber in order to test his theory (the apparatus is still in the Cavendish Laboratory), and found that he was right. This was only a month after the Joliot-Curies' publication. He called the neutral particle a 'neutron'. It fitted perfectly into the mosaic of what was known about the structure of the atom. 'The discovery of the neutron came naturally in the general line of advance marked out by Rutherford years before,' Chadwick said modestly. He saw it as the culmination of years of hard and sometimes tedious work by many men, and of Rutherford's inspiration. However, it got Chadwick the Nobel Prize and his later work during the war was rewarded by a knighthood. 'Chadwick's discovery of the neutron was truly in the Rutherford tradition,' said Blackett, 'and needed little apparatus but much inspiration and physical intuition. Chadwick's paper announcing the discovery describes simple well-designed experiments and is a model of clear physical thinking.'

It did not take long now until the part which the neutron plays in the make-up of the nuclei of the elements had been worked out. There is only one element, ordinary hydrogen, which has no neutron in its nucleus; but heavy hydrogen, one of its isotopes, has one neutron besides its proton. Helium (atomic weight 4) has 2 protons and 2 neutrons. Lithium, the lightest metal (atomic weight 7), has 3 protons and 4 neutrons. Iron (atomic weight 56) has 26 protons and 30 neutrons. Uranium, the heaviest element in nature (atomic weight 238), has 92 protons and 146 neutrons; it is 'unstable', but its lighter isotope, uranium 235, with three neutrons less in its nucleus, decays at a much faster rate and is therefore now used as an 'explosive' in atom bombs—and as a fuel in nuclear power stations.

The neutron, which, in Rutherford's words of 1920, can 'freely move through matter' and which 'cannot be contained in a sealed vessel', is of course an ideal sub-atomic 'bullet' for shooting up nuclei because it can penetrate quite easily through the shells of electrons around them, being neither repelled nor attracted by negative or positive particles. With the

discovery of the neutron, therefore, atom-smashing became the new fashion in physics. In America, the University of California built a small machine, called the 'cyclotron', for the head of its radiation laboratory, Professor E. O. Lawrence. This little device was the ancestor of some of the giant particle accelerators which have since been built in the Old and the New World. Lawrence had come to the conclusion that protons could be speeded up electromagnetically to great velocities, thus making a powerful missile for splitting nuclei. The cyclotron is based on the simple principle of the swing: by giving it a series of little pushes you can make it reach the greatest possible height. Thus, the ions are made to rotate between the poles of a strong electromagnet and are given a series of pushes in the form of shocks of alternating current until the maximum speed is reached; then the ions are released and shoot out at the target.

In 1940, Sir James Chadwick, then at Liverpool, joined a committee under the chairmanship of Sir George Thomson, J. J.'s son, set up to investigate whether it would be possible to produce an atomic explosive. Chadwick carried out the measurements. Later, when a whole team of British scientists —and Continental ones, who had fled from Hitler—moved to Los Alamos, in the New Mexican desert, to work in strictest secrecy on the development of such a bomb, Chadwick was the leader of the team from Britain. After the war he returned to Liverpool and, in 1948, to Cambridge, to become Master of Gonville and Caius College, a position which he held until 1958.

IX

The Machine Age of Research

It was no mere chance that the man who, more than anyone else, helped to usher in the machine age of research, John Douglas Cockcroft, worked for two years as a college apprentice in the Metropolitan-Vickers factory in Manchester—winding armatures, assembling switchgear, testing dynamos and electric motors—before entering the Cavendish Laboratory. He presented himself at the age of twenty-five to Rutherford in the autumn of 1922 because he wanted to read for the Mathematical Tripos. He had already seen and heard Rutherford many times when he studied mathematics at Manchester University; for 'light relief', as he called it, he attended Rutherford's lectures in physics. Then the war of 1914 interrupted Cockcroft's studies; for two years he served with the field artillery in France. 'When the war came to an end,' he recalls, 'I expected to have forgotten all the mathematics I had learned before my three years in the Army. However, I found that as soon as I started working again at the Manchester College of Technology, my mathematics came back with a surprising completeness.' He also read physics, but Rutherford had already gone to Cambridge. In 1920 he joined Metropolitan-Vickers as a college apprentice.

Cockcroft would, no doubt, have made his way in life as a successful electrical engineer. But something stronger than the desire to embark on an assured industrial career attracted him to research. He spoke to his professor at the Manchester college about his problem, and the result was that he travelled to Cambridge with a letter of introduction to Rutherford.

'I saw him in the old Maxwell wing of the Laboratory and found him sitting, as he often did, on a stool,' says Cockcroft. 'He received me in a very kindly fashion and gave me authority

to devote such time as I could spare from mathematics to work in the advanced practical class in the laboratory.' Best of all, Rutherford promised to take him on as a research student if he gained a first in the Tripos.

This he did, and Rutherford took him on. The young Yorkshireman did not expect an easy life; his father, a small manufacturer, had five sons, and John was now expected to fend for himself. He managed to scrape through on some modest grants. Like all of Rutherford's 'boys' he had to turn his hand to whatever craft or technique was required to make some piece of equipment—high-vacuum work, glass-blowing, magnet-building, electronics and so on. Cockcroft said later that these experiences proved to be 'of first-rate value for the applied physics of the war years'.

There was a ritual in Rutherford's room every day at four in the afternoon—counting alpha-particle collisions. The set-up was still more or less the same as that described by a visitor in 1919 (see Chapter VI). Two of the research students were brought in, there was half an hour's tea-time in the darkened room, Rutherford talked about this and that, Crowe arranged the apparatus, and then everybody took turns of a minute each to look through the microscope, counting the faint scintillations on the zinc-sulphide screen.

Rutherford used a natural source of radiation, shooting out its alpha particles at an almost leisurely pace. Was there no way of speeding them up or increasing their number? 'It has long been my ambition,' said Rutherford in 1927, 'to have available for study a copious supply of atoms and electrons which have individual energy far transcending that of the alpha and beta particles from radioactive bodies. I am hopeful that I may yet have my wish fulfilled, but it is obvious that many experimental difficulties will have to be surmounted before this can be realized even on a laboratory scale.'

Two years later, Cockcroft decided to tackle that problem. He teamed up with a twenty-seven-year-old Dubliner, E. T. S. Walton, who had come to the Cavendish the same way as Rutherford himself in the 1890's—on an overseas research

scholarship out of the 1851 Exhibition Fund. Cockcroft's idea was to pass an electric discharge through hydrogen to obtain a good supply of protons, and to accelerate them in a very strong electric field; these 'bullets' would then be aimed at a target of lithium or boron, two light-weight metals. The protons would hit the nuclei of the metal and cause a transmutation. This would, if the experiment succeeded, in fact be the first completely artificial transmutation of elements.

The task appeared formidable at first. But just at that time, a twenty-six-year-old theoretical physicist from Leningrad, Grigori Gamov, paid a visit to his countryman, Kapitza, at the Cavendish, and told him of a theoretical study of the way in which charged alpha particles escape from atomic nuclei. This suggested to the British scientists the possibility of a reverse process by which charged protons of a few hundred thousand volts' energy could be made to enter atomic nuclei.

Cockcroft–Walton's machine turned out to be the most expensive piece of apparatus ever installed at the Cavendish up to that time. Its main parts cost no less than £500, a sum which appeared to everybody at the Laboratory quite astronomical. Cockcroft got part of it with Rutherford's help, but the costly transformer and vacuum pumps were eventually paid for by the Royal Society, which the two young men had approached.

The particle accelerator—as this type of machine was called later—presented formidable high-vacuum problems; but this was what workshop-trained Cockcroft revelled in. He got a couple of disused petrol-pump cylinders, which became the heart of the apparatus; they were fitted on top of each other so that they looked like two stovepipes. The large transformer was set up in one corner of the room; this was to step up the current coming from the mains. A system of condensers was to store up the electric energy; rectifiers made the current flow in one direction only, and increased the potential to 300,000 volts. The petrol cylinders were fitted with steel tubes connected to the high-voltage set.

The targets for the protons were the metals lithium and

boron. Lithium has two isotopes, atomic weights 6 and 7. Under proton bombardment, the lithium was expected to split up; a proton would occasionally enter one of its nuclei, and the result would be a beryllium isotope, atomic weight 8. This, however, was unstable; it would instantly break up into two fast alpha particles—helium nuclei, atomic weight 4—which would fly off in opposite directions.

One morning in April 1932, the machine, which had taken almost three years to build, was started up. Ritchie Calder, who visited the Cavendish at the time, described what the scene looked like:

'Ernest, Lord Rutherford of Nelson, pushed aside a Geiger counter, a soldering iron and a clutter of bits and pieces, and hoisted his six-foot frame and its matching bulk on to the laboratory bench. With his hat tipped to the back of his head and his feet dangling, he might have passed as a farmer at a cattle roup in his ancestral Perthshire or at a flax-sale in his native South Island, New Zealand.

' "Take over, Cockcroft," he said, "it's your show."

'In the darkened hall, switches were thrown. The generators warmed, with the hum of a gathering storm. There was the throb of the pumps as they sucked the air out of the vacuum tubes. Lightning crackled and flashed as the high-tension spheres sparked. A tall glass pillar glowed with a luminous blue haze. Presently there was a clicking sound, and a counter, like a mileage recorder in a motor-car, began to clock-in the fragments of the splitting atoms. . . .

'Compared with the high-voltage accelerators which have now been installed at the Cavendish and elsewhere, the apparatus was engagingly primitive. They had used plasticine, biscuit tins, and I suspect sugar crates. The business end of the whole operation was housed in what looked like a packing-case in which you had to crouch to enter. Once inside you closed the curtain and through a microscope watched the luminous tracks of the shattered atoms, which at the same time were clicking their arrival on the Geiger counter, and automatically counting themselves.

' "There," said Lord Rutherford to me, scrambling off the laboratory bench, as the blinds were raised and the experiments ended, "that should convince you that the atom will always be a sink of energy and never a reservoir of energy."

'Cockcroft, with perhaps prescience of his own future activities, challenged the "Prof.", but Rutherford was obstinate on one of the few mistakes which he made in a lifetime of uncanny atom-insight and foresight. What he meant was that in order artificially to split the atom we would have to apply more energy than, in practical terms, we would get out.'

It was true: Rutherford did not believe—and he said so on several occasions—that there was much chance of nuclear energy ever becoming a source of industrially usable power; and he never talked about the possibility of using it as a weapon of war. Still, he must have had some lingering doubts. After one of these atom-splitting experiments, someone asked pensively, 'Where are we going from here?'

'Who knows?' replied Rutherford. 'We are entering no-man's land.'

Cockcroft himself later called those years at the Cavendish the 'Golden Age of Physics', with their rapid succession of discoveries. 'One month it was the neutron,' he wrote, 'another month the transmutation of the light elements; in another, the creation of radiation of matter in the form of pairs of positive and negative electrons was made visible to us by Professor Blackett's cloud chamber, with its tracks curled some to the left and some to the right by powerful magnetic fields.'

He could have added Bernal's work on the crystal structure of proteins, Bullard's study of the interior of the earth, Ratcliffe's and—from 1936—Appleton's work on the wave-reflecting layers of the atmosphere, which formed a solid basis for the development of radar. Nor should one forget the job of instructing yet another generation of young scientists in those fast-growing spheres of knowledge: C. T. R. Wilson did it until he retired in 1934 (to his home in Scotland, where he lived to the ripe old age of ninety); G. F. C. Searle was still around, running his property-of-matter class until he was eighty—his bicycle

had its customary place at the wall of the Laboratory, and once he exhibited proudly a new pair of mudguards: 'That'll mean another three miles per hour!' Then there was Dr Alex Wood, a splendid lecturer and an impressive personality; he was a sincere Christian and a Socialist, and once stood as a candidate for Cambridge.

In 1936, the motor-millionaire Herbert Austin gave Cambridge University, in appreciation of Rutherford's work, a quarter of a million pounds for a new building. With his usual enthusiasm, Rutherford threw himself at once into the job of planning an extension for the Cavendish, and making lists of required equipment. There was, for instance, the need for a cyclotron and for a more powerful, streamlined Cockcroft-Walton accelerator. The machine age of research should not find the Cavendish straggling in the rearguard of science.

Rutherford was not to see all the wonderful things that Lord Austin's money was able to buy. He died after a very short illness, at the age of sixty-six, in October 1937. He found his last resting-place at the side of Isaac Newton in Westminster Abbey.

A great chapter in the history of the Cavendish had come to an end. Would there ever be another one comparable in achievement?

X

The Cavendish at War

For a time it certainly looked like a crisis of the Cavendish as a leading research institute. No successor to Rutherford was appointed for a good many months. There had been a general exodus of talent: Blackett had gone to Manchester, Oliphant to Birmingham, Chadwick to Liverpool, Bernal to the Royal Institution in London. In fact, Rutherford's young men who had taken chairs at other universities moulded British physics everywhere in the Cavendish tradition—perhaps the Laboratory's greatest achievement!

At last, in February 1938, Sir Lawrence Bragg was elected to the Cavendish professorship—succeeding Rutherford again at Cambridge as he had done at Manchester nearly two decades earlier. He had continued with his X-ray investigation of crystal structures and alloys in Manchester, and it was clear that the Cavendish would greatly benefit from Bragg's appointment, which widened its scope. He brought his crystallography laboratory with him, thus associating the Cavendish with a relatively new and very important branch of physics, which he had virtually created together with his father, Sir William Bragg. Apart from the impact of this work on atomic and biological research, it had become extremely valuable in industry; although Sir Lawrence was not a nuclear physicist, his election proved to be of immense value to the Cavendish.

Bragg was very much impressed by Cockcroft's personality—'incredibly clear-headed, unflappable, business-like' he called him—and got him appointed as second professor. But Cockcroft was not given much time to take up his duties; or rather, he felt that there were even more important things to do than teach at the Cavendish. The clouds of war were gathering. While the workmen moved in to start the new research wing,

four floors high, financed by Lord Austin's gift, Hitler plunged the world in deepest gloom with his threats of war over the Sudetenland. There was a brief reprieve lasting less than a year, but there was a strong feeling among many scientists that it was high time to prepare for the worst.

John Cockcroft was the main mover in a great scheme which was to be of tremendous assistance to Britain's war effort. During a lunch with Sir Henry Tizard, then Rector of the Imperial College and chairman of the Committee of Research on Air Defence, at the Athenaeum Club in London, Cockcroft learnt the details of a top-secret device called 'radio detection and ranging', radar for short. It was still very much in its development stage, and Sir Henry suggested that some of the Cavendish people could help a great deal; Blackett was already working on Tizard's committee. A few months later, Cockcroft paid a visit to the secret research station on the east coast where the inventor of the system, Robert Watson-Watt, and his team were at work. Watson-Watt explained to Cockcroft what radar might be expected to do in case of war, and Cockcroft was 'thrilled with these visions', as he wrote in his diary.

He drew up a list of scientists at the Cavendish whom he believed of value to the war effort, and submitted it to the defence authorities. The result was that, as Bernal put it, 'the Cavendish gang ran the war scientifically and technically'. Young Cavendish people were among the first to be trained in radar operation, and manned the early radar stations. Cockcroft himself and a number of colleagues from the Cavendish, from the Clarendon Laboratory, Oxford, and from other university research institutions—altogether eighty or ninety—moved to Bawdsey Manor near Orford, to Swanage, Hampshire, and eventually to Malvern, the new headquarters of radar development. No doubt, Britain's lead over Germany in radar technique was largely due to the young men from the Cavendish. 'During the war you could see the spirit of the Cavendish burning fiercely in huts and stables on the Swanage headland and Hampshire coast, generating the micro-wave radar which contributed so much to our victory,' wrote Cockcroft later.

Early in 1944, he received a phone call from London, asking him to go at once to Montreal—and to build the first atomic reactor in Canada. This was the Chalk River project which ran, during the last year of the war, concurrently with the famous 'Manhattan project', the creation of the first atomic bombs. It was at Chalk River that Cockcroft gained the vital experience which enabled him after the war to build up, from scratch, Britain's entire atomic-energy enterprise, with its mighty nuclear power stations now going up at the rate of one every eighteen months. In 1946, Cockcroft was appointed head of the atomic-energy centre which was to be built at Harwell, on the site of a disused R.A.F. airfield.

For twelve years, John—now Sir John—Cockcroft controlled Britain's atomic development, but in 1959 he returned to Cambridge as Master of its new Churchill College.

Meanwhile, at the Cavendish, the war years had effected many changes. Most of the research work stopped, but some of the teaching went on; a new venture was electronics, or the 'radio school', which turned out young scientists in various branches of wireless work for military purposes.

Sir Lawrence Bragg was most anxious that the Austin wing should not fall by the wayside. Cockcroft and the architect had worked out the plans, but there was the danger that the authorities would have the building stopped for the duration of the war. So Bragg promised the Army and the Navy that if he were allowed to complete the extension he would put it at their disposal. This offer was accepted. In the autumn of 1940, the Austin wing was opened—and the War Department moved in.

One day in June 1940, when the world was watching with dismay the tragedy of France, two foreigners arrived at the Laboratory. Their luggage consisted of two small suitcases with their personal belongings and a large box, weighing about 2 cwt. They were French scientists who had been sent from Paris, shortly before the Germans marched in, by Professor Joliot-Curie; they had smuggled out 165 litres of heavy water—the precious fluid which the Germans wanted for their own attempts at creating a nuclear bomb, now denied to them.

Apart from eight months in Canada in 1941, when he acted as scientific liaison officer between that country and Britain, Bragg remained at the Cavendish and again took up a special line of research which had been of great value during the first world war: sound ranging. His father had been one of the creators of the Asdic system, so called after the Allied Submarine Detection Investigation Committee which sponsored that research line. It was based on the technique of emitting high-frequency, inaudible sound pulses, which come back as an echo after striking an object such as a submarine. The system was also used during the second world war, and was responsible for the high percentage of 'kills' achieved by the Allied antisubmarine forces, with Sir Lawrence acting as adviser to the Admiralty.

In World War I, Sir Lawrence had already worked out another system, that of sound-ranging enemy guns on land. It proved again highly successful in World War II, against the German Afrika Korps in Libya and Sicily. The basic idea was to set up half a dozen microphones in a semicircle to determine, by the direction of the sounds and the different times at which they reached the microphones, the exact distance and location of an enemy gun or battery.

After the war, when the laboratories and lecture rooms at the Cavendish filled again gradually and the War Department moved out of the new Austin wing, a young researcher by the name of Martin Ryle came from Malvern, where he had worked on radar for six years. He was uncertain whether he should 'go into' nuclear physics or take up research into an entirely new field called radio astronomy. Bragg reflected on the problem for a while. The Cavendish's great tradition in the field of atomic physics, started by J.J. and Rutherford, had suffered a great loss by Cockcroft's departure. It was doubtful whether there would be much wisdom in trying to concentrate again heavily on nuclear research—although the Cavendish could now boast its own cyclotron, which its scientists had designed.

The problem was that nuclear research had become very

expensive; it was a matter of costly and complicated apparatus. Elsewhere, that kind of equipment was already in existence. Yet up to 1955, about 40 per cent of the work at the Laboratory was still in this field. Professor Otto R. Frisch, the brilliant German-born physicist, nephew of Otto Hahn's collaborator Lise Meitner—closely associated with the discovery of uranium fission—was working at the Cavendish with a small team, which included Denys Wilkinson and James Macdonald Cassels.

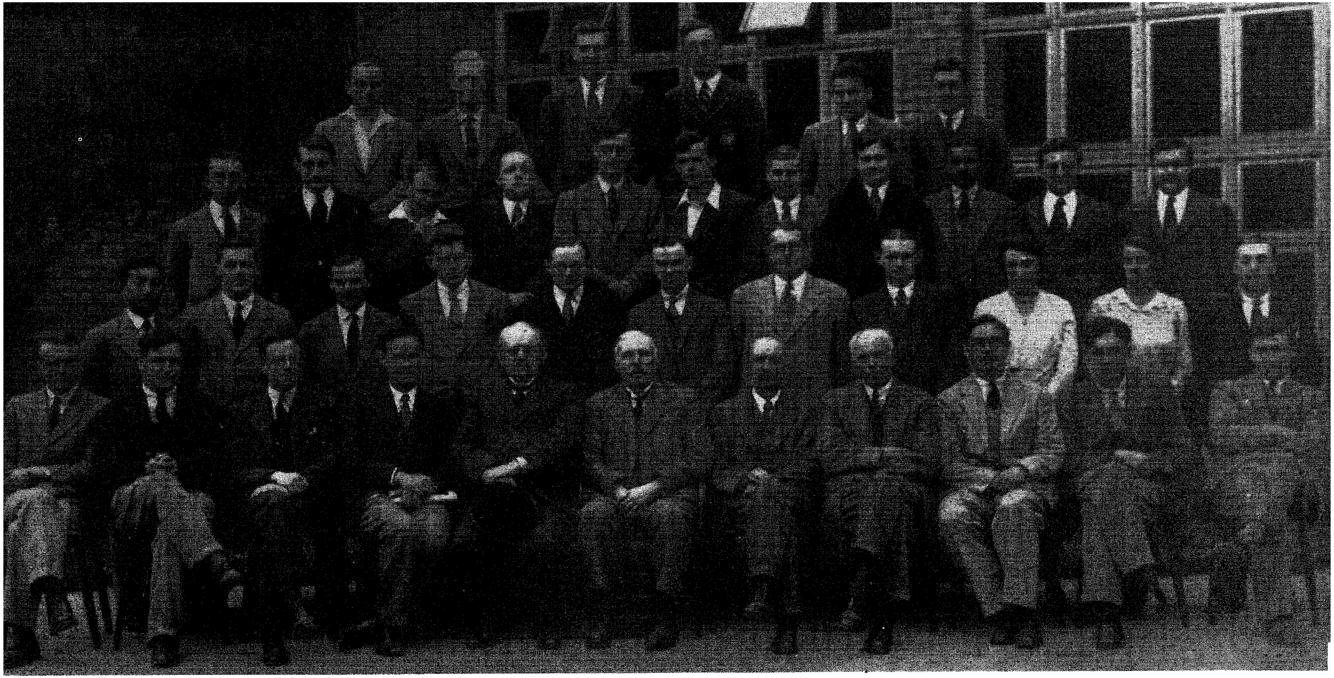
On the other hand, the exploration of some entirely new field of physical research would be exactly in the Cavendish tradition. Ratcliffe had aroused young Ryle's interest in radio astronomy. The story of that new branch of science went back to 1932 when Dr Karl Jansky, working at the Bell Telephone Laboratories in America, picked up radio waves which seemed to come from some invisible source in the sky. For several years no one cared enough to investigate this phenomenon; besides, its study became feasible only with the highly sensitive radio instruments developed during the second world war. Two British scientists, however—Hey and Sander—working independently, studied radio emissions from the sun and the Milky Way, and Hey received radar echoes from meteors.

Dr. A. C. Bernard Lovell of Manchester University became the first British University scientist to investigate the matter. He had been one of the Watson-Watt radar team during the war. Obtaining some Army surplus equipment, he moved to Jodrell Bank, Cheshire, where the University's Botanical Department, had its field station. Most of the equipment was installed in the manure shed. The original idea was to use radar techniques to track down showers of cosmic rays; this was, of course, the very special field in which Blackett, then also at Manchester, was the leading international authority. Also, the American Army Signal Corps had succeeded in getting radar echoes from the moon in 1946. Lovell wanted to take up these experiments.

It was in 1947 that he built his first, primitive 'radio telescope' at Jodrell Bank, and he soon found that there were powerful sources of emissions in the constellation of Cygnus—which

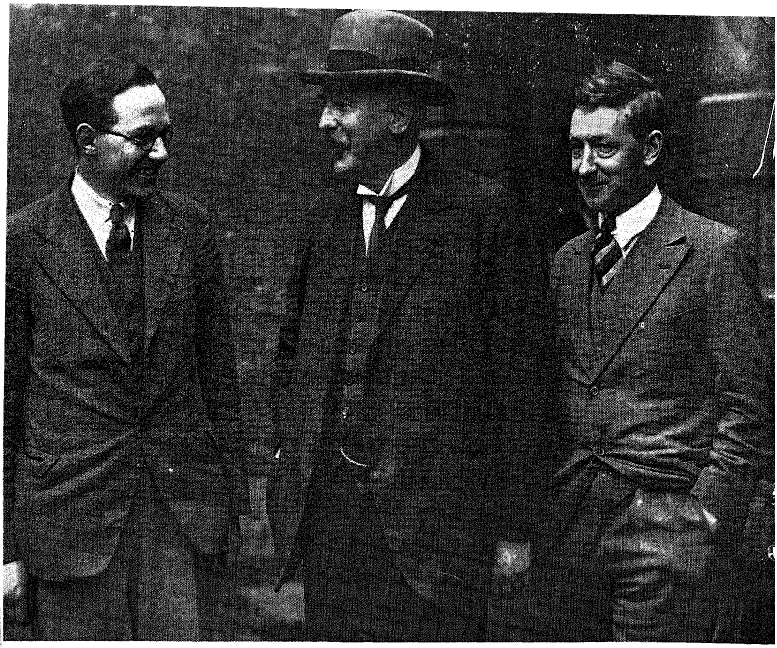
had been first observed by Hey during the war; later, Lovell discovered in our neighbouring galaxy, the Andromeda nebula, many invisible suns, or 'radio stars', which kept 'broadcasting' on a wavelength of 1·89 metres.

'Ratcliffe is right,' said Sir Lawrence to Ryle. 'Take up radio astronomy!'

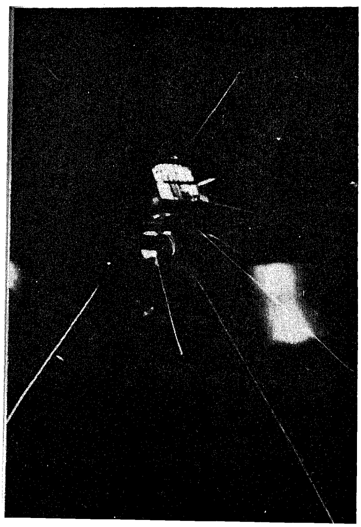


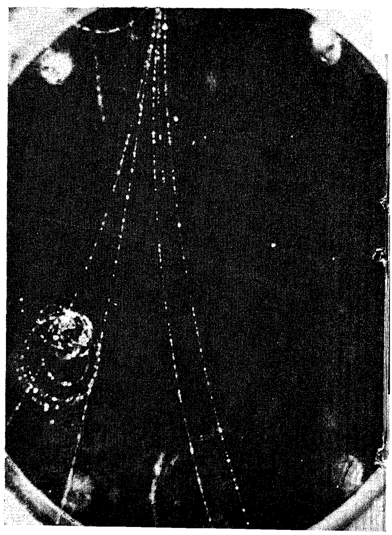
XVIII. Professors and students at the Cavendish (June 1932).

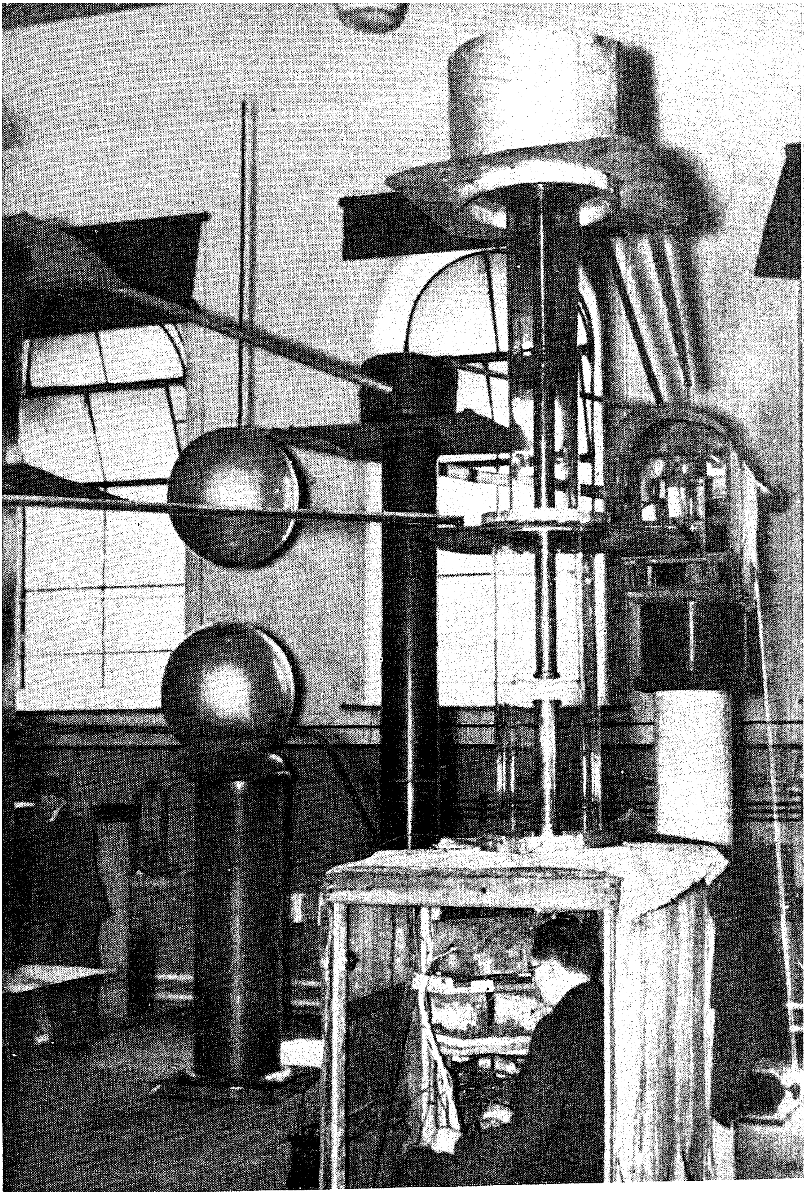
N. S. Alexander P. Wright A. G. Hill J. L. Pawsey G. Occhialini H. Miller
W. E. Duncanson E. C. Childs T. G. P. Tarrant J. McDougall R. C. Evans E. S. Shire E. L. C. White F. H. Nicoll R. M. Chaudhri B. V. Bowden W. B. Lewis
P. C. Ho C. B. Mohr H. W. S. Massey M. L. Oliphant E. T. S. Walton C. E. Wynn-Williams J. K. Roberts N. Feather Miss Davies Miss Sparshott J. P. Gott
. A. Ratcliffe P. Kapitza J. Chadwick R. Ladenberg Prof. Sir J. J. Thomson Prof. Lord Rutherford Prof. C. T. R. Wilson F. W. Aston C. D. Ellis P. M. S. Blackett J. D. Cockcroft



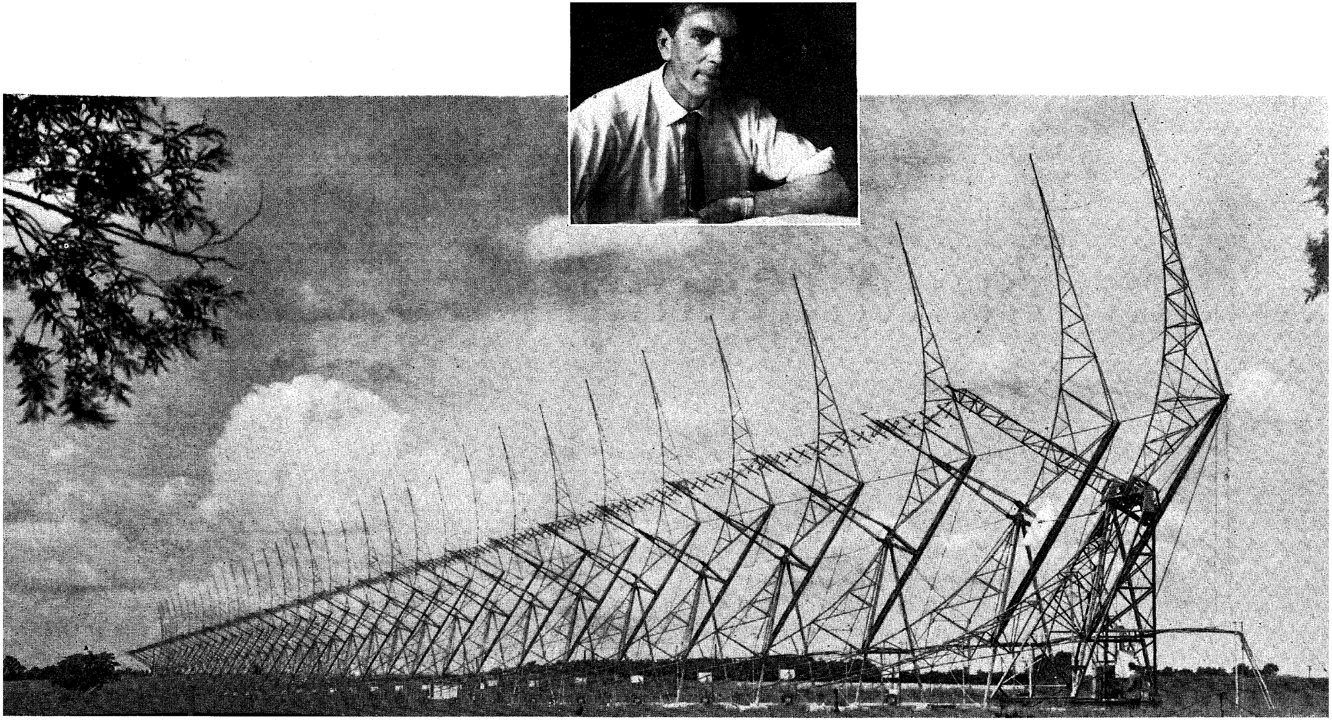
XIX, XX and XXI. (Above) *Lord Rutherford with John D. Cockcroft (right) and E. T. S. Walton, 1932. The picture was taken outside the Laboratory, immediately after the successful 'atom-splitting' experiments (see No. XXII).* (Below left) *Photograph showing the disintegration of lithium in Cockcroft-Walton's apparatus.* (Below right) *Photograph of a cosmic-ray shower in the cloud chamber.*







XXII. *Cockcroft-Walton's apparatus for the transmutation of light elements in 1932. Plasticine, biscuit tins, old petrol-pump cylinders and sugar crates went into the construction of this highly important machinery! In it for the first time a completely artificial transmutation of elements took place.*



XXIII. *The fixed aerial of the radio-star interferometer at the Mullard Radio Astronomy Observatory, University of Cambridge.* (Inset) *Professor Martin Ryle, the head of the observatory. It was opened in 1957 at Lord's Bridge, with two very large telescopes, as well as a number of smaller ones, and a present range of 9,000 million light years.*

XI

Probing into Time and Space

SIR LAWRENCE'S successor, who at the time of writing is still head of the Cavendish, is Professor Sir Nevill Francis Mott. He had worked for a year with Bragg in Manchester and then taken a leading part in building up the school of physics at Bristol. He is a theoretical physicist who worked on nuclear problems while in Cambridge, and turned to the structure of solid matter later at Manchester and Bristol.

'Solid-state physics' is a relatively new term, but its beginnings are as old as human civilization. When, for instance, Man learnt to smelt copper and bronze, and discovered that impure metals, alloys, are much harder and give a better cutting edge than pure ones, he laid the foundation of metallurgy. But it was only in our own century that scientists began to enquire into the properties of metals, and again it was the two Braggs, father and son, who started the ball rolling with their technique of X-ray analysis. As recently as 1934, there was no research into the 'ductility' of metals, their malleability, their hardening when they are hammered, and similar problems. The arrangement and rearrangement in heat and stress of the atoms of a metal, its crystal structure, questions of its shape and density, elasticity and volume—these are subjects which are of enormous importance to industry today, yet which science had hardly touched upon a generation or so ago.

Professor Mott found flourishing schools of crystallography and low-temperature physics in Cambridge, and he decided to build up a school of solid-state physics based on them. Under the leadership of Professor Pippard, Dr Shoenberg, Dr Taylor and others, the researches on the properties of electrons in metals, super-conductivity, and the mechanical strength of metals have achieved world-wide reputation; the practical

importance of this work is evident in many spheres. To the aircraft designer fatigue research is of overriding importance; to the electronic engineer the properties of electrons in metals and the phenomenon of super-conductivity, problems of magnetic fields and low temperatures as applied to metallurgy are of the greatest consequence—to quote only a few examples.

About one quarter of the present research work at the Cavendish, however, resulted directly from Sir Lawrence's advice to Martin Ryle to take up radio astronomy. Ryle put his heart into it; enthusiasm had to make up for the lack of money in the early years of this new branch of science. The first apparatus he built was no more than some lengths of wire strung up on insulators—which seemed quite ridiculous compared with the largest telescope in the world, the 200-inch giant at Mount Palomar.

Right from the start, Ryle decided to use a different method from that of Lovell's team at Jodrell Bank with their bowl-shaped type of radio telescope. His first radio telescope, set up on the outskirts of Cambridge in 1946, was an 'interferometer', basically a simple instrument consisting of a pair of aerials spaced a long way apart, and connected to a special receiver; the larger of these two aerials was fixed to the ground, the other one was movable so that the 'aperture' could be altered.

Fascinating problems tempted the small band of radio astronomers working in Europe and America in the late 1940's and early 1950's. One of the strongest radio sources was identified as the strange object called the Crab nebula, seen through an optical telescope as a dim patch of gas in the constellation of the Bull, so far away that its light takes 3,000 years to reach us. It is probably the remains of a 'supernova', a star which exploded, and was observed by Chinese astronomers in 1054. The gas is still expanding and sends out radio waves due to the extraordinary physical conditions produced. Other radio sources may also be the remnants of supernovae; many, like the one in Cygnus, which may be the result of a collision of two galaxies, are far beyond the limit of our own Milky Way.

The sun, too, is a radio source, and so is the planet Jupiter, due perhaps to vast storms raging in its atmosphere. Even Venus has been found to send out radio waves. As a rule, however, bright stars or planets do not emit radio waves of great intensity. It was the fact that the radio telescope discovered innumerable invisible sources—thus creating an entirely new map of the heavens—which has since allowed the exploration of space on a larger scale than ever before, and made this new instrument of scientific research so important. Moreover, astronomy suddenly ceased to be exclusively restricted to the hours of darkness and cloudlessness; the radio telescope can receive its messages from the universe at any time of the day or night, and in any weather. The radio waves from the Milky Way did not seem to originate in the stars at all but from interstellar space, including the great clouds of dust and gas in our galaxy which are ionized by hot stars; the interaction between ions and free electrons produces some of the radio waves detected, and some are due to the emission from hydrogen in cooler regions. This radiation occurs on a particular wavelength of 21 centimetres.

In 1955, the Cavendish's early days of radio astronomy came to an end when Ryle was granted £100,000 by the radio firm of Mullard and an additional sum by the Department of Scientific and Industrial Research to build a complete radio-astronomical observatory at Lord's Bridge, five miles south-west of Cambridge, on the site of a disused R.A.F. station, 180 acres in extent. Sir Edward Appleton opened it in the summer of 1957.

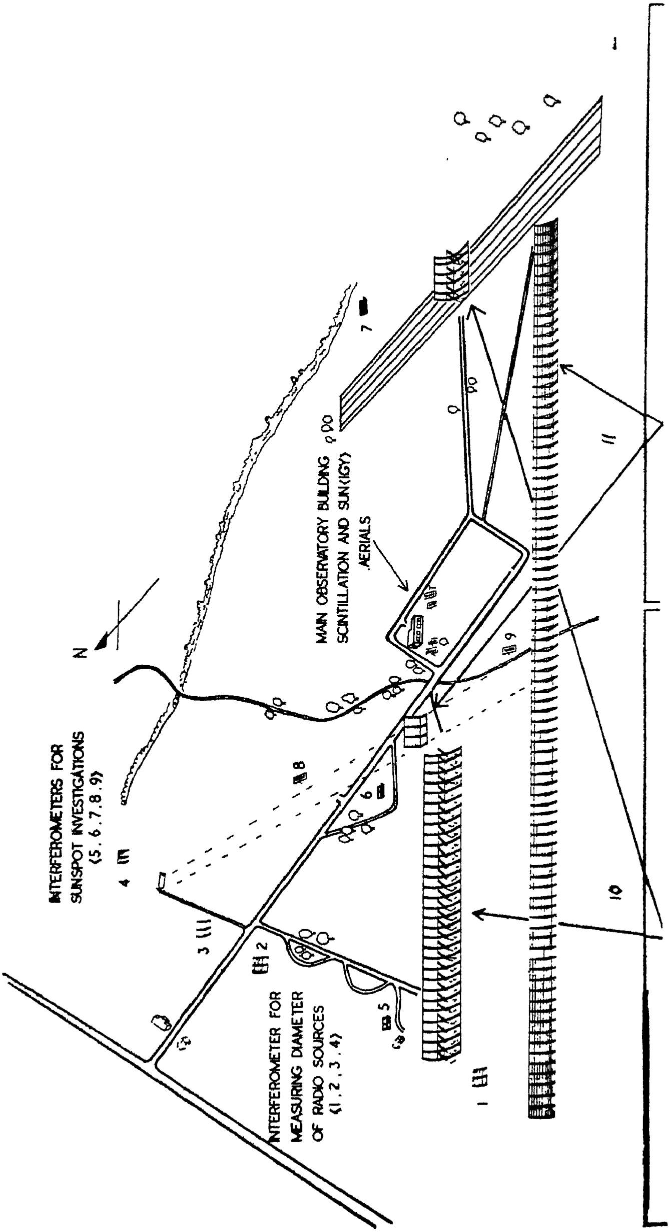
The observatory has two very large telescopes and a number of smaller ones. They are not 'general-purpose' instruments like the Jodrell Bank telescope, but special instruments designed for particular wavelengths and jobs; one large one is used mainly to receive waves from the Milky Way and the other to detect radio stars. But there is a whole series of other tasks being carried out at this observatory, such as the study of cosmic rays, the origins of which are still a matter of controversy. One theory says that they are produced somewhere in the depths of

the universe; another theory (held by the Russian astronomers) explains them as the result of sudden supernoval activities, of stellar explosions.

Nearer home it is the outer 'atmosphere' of the sun which is being studied at the Lord's Bridge observatory—it is quite detectable out to the orbit of the planet Mercury—and observations have also been made to detect the 'atmosphere' of the moon. This is, of course, so thin that it does not protect our satellite from meteorites, which must have contributed a great deal to the material of which the moon surface consists. A study has also been made of this surface material in order to determine its thickness—a question of vital importance to the first travellers to the moon, because they must know if they may expect to sink into cosmic dust up to their space helmets.

The interferometer for investigating radio emissions from the most distant radio stars is used on a wavelength of 1·7 metres and consists of two aerials, 2,600 feet apart, each in the form of a cylindrical paraboloid. It is designed to obtain the positions and intensities of about 10,000 radio sources in the northern sky. One of the structures is 1,450 feet long and 65 feet wide and is fixed to the ground; the other, 190 feet by 65 feet, can be moved along a 1,000-foot railway track laid along a north–south line. Both have reflecting surfaces of steel wires running along the length of the aerials; they are supported by parabolic frames 45 feet apart. This telescope is a 'transit' instrument, that is, it makes use of the rotation of the earth for scanning the sky. During operation the movable aerial is first set at one end of the rails and the receiver output is recorded during a period of twenty-four hours. The next day, the aerial is moved to another position along the track, and so on day after day until, after thirty days of observations, it has reached the end of its track. Each strip of the sky yields about 200,000 'readings' which are recorded on teleprinter tape; then they are fed into an electronic computer at the Cambridge University mathematical laboratory.

In this way it is possible to obtain the performance of a much bigger aerial than has actually been built; the detail obtained



Plan of Mullard Observatory, showing positions of radio telescopes

is equivalent to that from two paraboloids each 750 feet in diameter.

The nature of the 'radio stars' is one of the most exciting problems in modern astronomy. It is now clear that very few of them are actually 'stars' in the usual sense, and most of them are not even within our own galaxy; they are probably very distant galaxies with an extremely powerful emission of radio waves. They may well be of great importance in the study of the universe as a whole.

The other large instrument uses the same principle of 'synthesizing' a big telescope to map the intensity of radio waves from our own galaxy. Its fixed part consists of a 3,300-foot-long aerial, 40 feet wide, while the movable aerial is only 100 feet long and also 40 feet wide; this can be moved through a distance of 1,500 feet along its track.

Ryle has no plans to tackle a question which, however, some radio telescope may solve one day: is there any intelligent life somewhere in other solar systems? Astronomers have not much hope of discovering human-type beings on planets in our own solar system; but there are bound to be conditions favouring organic development on at least a few of the innumerable planets around the 100,000 million suns of our own Milky Way —to say nothing of the uncounted galaxies that make up the entirety of the universe. There is a good chance that somewhere intelligent beings have developed the technique of sending and receiving radio waves as we have done; and perhaps one day the radio astronomers may receive signals trying to 'say something'. But how could we communicate with our unknown fellow beings somewhere in space? A kind of mathematical language will have to be worked out, starting perhaps with an exchange of decimal numbers, followed by their powers and logarithms and the Pythagorean theorem, for mathematics is one of the few things which would apply anywhere in the universe. But even if we can arrive at a common language it will be a slow-motion conversation, for our correspondents will be very far away. The closest neighbouring sun in the Milky Way, Alpha Centauri, is five light years distant. We would need a

very powerful transmitter to penetrate such depths, and we would have to wait for at least ten years for an answer to our signals.

The Cavendish radio telescope can, however, receive the powerful emissions from radio sources in the universe from a much greater distance, and here we may—perhaps soon—find a definite clue to another question mankind has been asking for thousands of years: how did the world begin, and when?

The 200-inch telescope on Mount Palomar, which has the greatest range of any optical instrument, has been able to photograph a faint galaxy, moving away from us at a speed of nearly half the velocity of light, at a distance of 4,500 million light years—the limit of penetration with an optical telescope. The Lord's Bridge radio telescope, however, has a range of 9,000 million light years! Theoretically, that range could be extended still further, but the effective size of the aerials that can be built is limited. Still, even a 9,000 million light-year range yields fascinating information on the development of the universe.

'This is the new way in which cosmology is being studied,' says Professor Ryle. 'You can't, of course *prove* that a particular cosmological theory is right, but you may be able to prove that a particular theory is wrong. And I believe we have already disproved something.'

What is this something? It is one of the theories on the origin and development of the universe. Ancient mythology had a number of explanations, one for each creed and country; the Bible gives us a beautiful and poetic account of the creation of the world (and even an exact date); other religions tell a variety of stories about the origin of the world and its phenomena. But until now it had to be left to the individual whether he believed them or not, for science had no means of disproving them. Modern thinkers are mainly divided into two camps: the 'evolutionists' and the adherents of the 'steady-state' theory.

Some evolutionists suggest that the universe started in the form of an immense lump of matter of such density that a cubic inch of it must have weighed (in earthly terms) several million

tons; this 'primeval atom' began to disintegrate many thousands of millions of years ago, and has been expanding ever since, forming galaxies, stars, and solar systems.

The other theory assumes, in the words of one of its advocates, Professor Hermann Bondi, that 'the universe presents on the large scale an unchanging aspect. Since the universe must (on thermodynamic grounds) be expanding, new matter must be continually created in order to keep the density constant. As aging nebulae drift apart, due to general motion of expansion, new nebulae are formed in the intergalactic spaces by condensation of newly created matter.' This creation takes place at a uniform pace throughout the universe, but it must be imagined as going on at an extremely slow rate: one hydrogen atom per one litre of volume every 10^9 years. The 'continuous-creation' or 'steady-state' theory (the latter term is used by Professor Fred Hoyle for his variant of it) means that the universe never had a beginning and will never have an end, and if people could have been looking up to the sky from our earth thousands of millions of years ago it would have appeared to them little different from what it is now.

How can science decide which theory is correct? It seems an impossible task. Yet the radio telescope may be able to perform it. In fact, Professor Ryle said early in 1961 that he had come to the conclusion, on the strength of his research work at Lord's Bridge, that the steady-state theory must be wrong. He believed that he had observed, in the farthest depths of space about 9,000 million light years away, a much greater number of radio sources than the steady-state theory would permit. In other words, the universe was much more tightly packed with matter 9,000 million years ago—the radio telescope can, in fact, see the distant past as it looks into distant space! Now if the density of the cosmic bodies in that faraway corner of the universe was so much greater thousands of millions of years ago, the expansion theory seems to be right: that all matter in the universe came from that 'primeval atom', which exploded, dispersing its matter, which has been expanding ever since.

Professor Hoyle and his steady-state cosmologists have not

given up yet. They believe that a great deal of further evidence will have to be collected before one of the theories on the nature of the universe can be discarded. Professor Ryle's new radio telescope, to be completed in 1963 as the result of a Government grant of nearly half a million pounds, will provide many more data for which the astronomers are asking. It will consist of three parabolic aerials similar to the Jodrell Bank telescope, each 60 feet in diameter. Two of them will be fixed but free to point towards any direction in the sky; the third will move on rails and can also point in any direction. Used together, these three aerials will be able to map the emission of radio waves with greater accuracy than the older instruments, and Professor Ryle will be able to detect much weaker sources than previously. Under examination by this new instrument, some of the already well-known sources of radio emission may turn out to be very complex objects and not just single sources. In short, there will be enough work 'to keep the radio telescope happy for hundreds of years', says Professor Ryle.

Will it be one of the radio telescopes of the Cavendish that gives us the definite answer to one of Man's oldest questions—how the universe began, or whether it never began and will never end?

XII

Break-through at the Cavendish?

'THERE are some wonderful things being done today at the Cavendish,' Sir Charles Snow said in 1960. 'It is possible that we are just on the fringe of a tremendous break-through—just at a point where physics, chemistry, and biology meet. That may be happening in the Cavendish.'

Under Sir Lawrence Bragg, the work on protein structure, its analysis by X-rays, grew into one of the glories of the Cavendish. Bragg also got one of the first American electron microscopes for these investigations, and formed a team to work with it. This is still active, and it has developed a very finely focused X-ray electron microscope which gives a three-dimensional picture.

When, in 1953, Sir Lawrence was appointed Director of the Davy-Faraday Laboratory at the Royal Institution, London, he organized his new team so that it formed one single research group with that at the Cavendish under the leadership of Dr Max Perutz, who came to Britain as a refugee from Hitler-occupied Austria in 1938 and was picked by Sir Lawrence as one of his closest collaborators at the Laboratory after the war. Meanwhile another 'molecular-biology' team had begun to investigate the problem of heredity in 1949. Its members were Dr Francis H. C. Crick, born in Northampton in 1916, a physicist who worked on magnetic mines for the Admiralty during the war; Dr S. Brenner, who came to England from South Africa; Mrs L. Barnett and Dr R. J. Watts-Tobin.

Already in 1953, Dr Crick and an American scientist, Dr J. D. Watson, suggested a new theory about the structure of the 'deoxyribonucleic acid', DNA for short, the actual substance of the genes—the theoretical units of heredity which are, in fact, items of information passed on from the living cell's ancestors to

subsequent generations. The genes instruct the cell to produce a certain kind of protein, which is its most important substance. The question was, in what chemical 'language' or 'code' this information was transmitted; therefore, the cracking of the genetic code was the main object of this work.

Each individual gene consists of a certain length of DNA, which is a long, chain-like molecule; and each gene's item of information is 'spelt out' in four kinds of chemical bases—usually adenine, cytosine, guanine, and thymine—attached to the DNA chain. One gene is thus represented by a certain sequence of these four bases. The genetic orders to the cell are issued by 'messengers' consisting of 'ribonucleic acid' (RNA); they form replicas of the four gene bases, attach themselves to particular parts of the living cell called ribosomes, and thus cause the cell proteins to assemble themselves in the order prescribed by the genes.

It is this code of instructions, therefore, which controls the development of every organism, from the humblest plant to Man—as an individual and as a member of its, or his, species; thus the cracking of the code must reveal one of the basic secrets of organic life. In 1961, two American scientists announced at the Biochemical Congress in Moscow that they had been able to 'translate' just one 'letter' of the code. A few months later, Dr Crick and his colleagues at the Cavendish published their latest discoveries.

The Cavendish team attacked its great problem by experimenting with abnormal varieties of a bacteriophage, a virus which attacks bacteria. By treating the virus with certain chemicals, they succeeded in *knocking out* one 'letter' of the code they wanted to crack. As a result, everything went wrong when the coded message arrived in the cell. Then they *added* a 'letter' to the code. Again there was confusion; the code did not make sense.

The team assumed that there must be some fixed number of bases which formed 'words'. But how many letters formed them? When one mistake was introduced by chemical means, the code went wrong; when a second mistake was introduced, it

was nearly right again, but not quite; but when a third mistake was introduced, the code worked again. Thus it could be assumed that the code 'words' consisted of three letters each; the letters were, of course, represented by the chemical bases.

The way in which these experiments were carried out can be made clear if we assume that the normal sequence of letters is A B C—as follows.

Normal sequence: A B C A B C A B C A B C . . . .

If one mistake is introduced (represented by an out-of-turn B), the code is thrown out of gear.

One mistake: A B C *B* A B C A B C A B . . . .

After the introduction of a second mistake, the code would be something like this:

Two mistakes: A B C *B* A B *B* C A B C A . . . .

But after the third mistake the whole three-letter code has been shifted by one 'triplet', and works again.

Three mistakes: A B C *B* A B *B* C A *C* B C A B C . . .

This, of course, is no more than the basic grammar of the genetic language, but its detailed interpretation is now only a matter of time. We may not yet see what practical effect this research work could have. The scientists are not concerned with possible everyday uses of their discoveries, although some science-fiction writers have let themselves go in their fanciful predictions of what society would come to if one day heredity could be not only completely understood but controlled. Shall we then be able to create masterbrains and monsters, supermen and dumb, obedient slaves at will? Or shall we confine ourselves to breeding men, animals, and plants that are resistant to diseases and thoroughly fit to cope with the risks of existence?

Whichever way mankind chooses, the annals of science will record that the decisive break-through began at the Cavendish in the 1960's.

* * *

It has been said that the Cavendish Laboratory is as old as the age of science in modern civilization. Born out of the need

for scientific education and research in England's industrialized society, the Cavendish has interacted vigorously with the forces that have transformed mankind's way of life in these nine decades; it has fulfilled its promise many times over, justified the highest hopes, and established itself as Britain's, if not Europe's or the world's, leading research institution. It has time and again proved wrong the voices which declared that the Cavendish's 'great period' was over—at the outbreak of the first world war, in the late twenties, in 1939—by embarking, out of the blue it must have seemed to outsiders, on some new and unexpected scientific venture, producing results of momentous importance now in this field, now in that, from Maxwell's and J.J.'s time to Mott's and Ryle's.

Yet there still persists a strong tradition, a pervading atmosphere of sincerity and comradeship among the teachers and scholars, the already famous and the mere beginners, which seems to be the *conditio sine qua non* of continuity on a persistently successful level. 'One cannot plan the work of a research laboratory on the assumption that Rutherfords and Faradays will be conveniently born to inhabit and work in it,' says Blackett. 'Laboratories must be planned for the normally gifted student, and a good laboratory might be held to be one where normal men achieve great things.'

This, perhaps, is the secret of the Cavendish, and the reason why in that 'nursery of genius' peaks of achievement have been reached at almost regular intervals. There is something essentially English about the Cavendish atmosphere, an imperceptible sliding of the past into the present and the future. They still speak about 'Rutherford's laboratory' as though the great man were still working in it (girls are now making models of molecule structures in the room); there is still the desk that has been used by all Cavendish Professors from Maxwell onwards (not long ago it was moved from a wall where one set of drawers had been inaccessible, and screwed up at the back of one of them was a ball of paper which had lain there for over eighty years—a list headed 'Gentlemen working in the Laboratory, 1877').

Martin Ryle has inherited the room where Rutherford, Bragg, and Ratcliffe worked; it has hardly changed in the course of time. Many rooms are still untouched by a decorator's hand and somewhat stuffy; age-old equipment, much of it home-made, fills the corners. In the dark-brown lecture room you can still see a forgotten aluminium ball which was used during the war, suspended from a barrage balloon, in radar research; yet some of the greatest physicists of our century lectured here. In another room you may find some unprepossessing piece of machinery such as an ancient laundry mangle used for wire-coiling—but all this does not mean, of course, that there have been too few changes. The latest equipment is there too, as you might find it in any modern American or Continental laboratory.

The growth of the Cavendish is shown by a comparison of figures. In 1913–14, there were a mere 25 research students; today there are 170, and about 100 undergraduates pass out in physics every year. It is no exaggeration to say that it has trained most of Britain's outstanding physicists, and the universities and research laboratories of the whole world are full of former Cavendish students and researchers. While in the 1920's the Cavendish was more or less a single group of mainly individual workers, all studying the atomic nucleus in one or the other of its aspects, the Laboratory today covers several different subjects, each with a distinct group of workers, each demanding a different theoretical background—solid-state physics, molecular biology, low-temperature physics, X-ray crystal analysis, radio astronomy, geophysics. Professor Mott—who was knighted in 1962—has been responsible for much of this swing to new fields of research.

It is useless to speculate on the Cavendish's future achievements, just as it would have been impossible in the past to predict into what no man's land the next scientific sally would lead. But the great advantage at Cambridge is that many different disciplines are here close together.

But is the mere fact of a new scientific achievement a good thing in itself? Since the first atomic bombs fell on Japan,

mankind has lived in the shadow of that terrifying means of destruction which one day could put an end to its very existence. Are we mature enough to be trusted with such dangerous toys? Or should the rulers of the world be urged to take a leaf out of the book of the Chinese emperors who, until half a century ago, forbade all discoveries, and any spreading of information about them, throughout their realm? Should there be, as some people have suggested quite seriously, a moratorium of all scientific progress until mankind has developed, ethically and politically, a sense of responsibility that must go with the development of the fantastic forces put at its disposal?

I think that the last word should be that of Professor Mott, the holder of the Cavendish chair:

'It is only too clear that, in this age of nuclear energy, antibiotics, and space travel, science is your business, whoever you may be,' he said to students at the University of Virginia in 1956. 'Too much of your money is spent on it, and the results affect you too much, for you to be indifferent to what is done. . . . We whose business is education have to concern ourselves with this problem, how we are to ensure that the new generation, who grow up to be administrators, political leaders, and businessmen, shall have a proper understanding of this science which affects their world so profoundly. . . . What we want to avoid, surely, and what to some extent we have, is a society of two mutually suspicious classes: the scientists, engineers, and technologists who do the work and set the rate of advance, and the administrators, soldiers, salesmen, security officers, and common men and women who know that we have to have science but who do not understand how the community should use it.'

There seems indeed no other way but to develop that understanding, and with it our sense of responsibility, while the progress of science takes its course for better or worse. We cannot stop it, and we must not hold the scientist responsible for our own failure to put his achievements to the best possible use.

You will also e

The Thirteen Steps to the Atom

by Charles-Noël Martin

This book is about the fantastic world we cannot see with the naked eye. In 118 marvellous photographs it shows objects of increasing minuteness from snowflakes, measurable in tenths of a centimeter, to electrons, measuring less than a ten-million-millionth of a centimeter! Between these extremes, a wide variety of other subjects is shown: silk threads on a cocoon, a section of mahogany, the root of a mouse hair, diatoms, nickel oxide crystals, viruses at work, the *skin* of a microbe.

Almost everyone, whether versed in science or not, will find these photographs fascinating. Many readers will also marvel at the fantastic beauty of the world they reveal, and for some (e.g., textile designers, architects, interior decorators) its patterns can be an inexhaustible source of inspiration.

The photographs, however, are not the whole of this book. In a clear and simple text, the author, a professional scientist, gives much fascinating information gathered in the course of man's "unending quest in pursuit of that final reality we can never fully grasp."